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Modeling Fog Oil Obscurant Smoke Penetration Into Simulated Tortoise Burrows and Bat Colony Trees

Mark Guelta and Harold E. Balbach

October 2005

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Modeling Fog Oil Obscurant Smoke Penetration Into Simulated Tortoise Burrows and Bat Colony Trees

Mark Guelta

U.S. Army RDECOM
Edgewood Chemical Biological Center
Aberdeen Proving Ground, MD 21010-5424

Harold E. Balbach

Construction Engineering Research Laboratory
PO Box 9005
Champaign, IL 61826-9005

Final Report

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ABSTRACT: The gopher tortoise (*Gopherus polyhemus*) and the Indiana bat (*Myotis sodalist*) are species found on many military installations. The Indiana bat is endangered throughout its range, and the gopher tortoise is threatened in its westernmost distribution and at risk everywhere else. On installations where troop readiness training is conducted, an important component of realistic troop readiness training is the generation of obscurant material and the conduct of maneuvers under obscurant cover. Fog oil has long been deployed for visual obscuration training, and the effect of such obscurants on these species is unknown. As a preliminary step prior to instituting toxicological studies, a laboratory simulation was performed of the capability of the fog oil smoke to penetrate the living space of these species, the tortoise burrow and the hollow-tree location of a bat maternity colony. The fog oil smoke did not enter the simulated tortoise burrow in significant concentrations, but smoke concentrations in the simulated tree cavity approached ambient levels. This suggests that tortoise burrows do not need to be studied in situ, and that tortoises may be considered protected while in the burrow. Bat maternal colony sites, however, should not be considered protected from smoke entry to any significant degree.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

*_Système International d'Unités_ ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for Headquarters, Department of the Army, Assistant Chief of Staff for Installation Management, under RDTE project number A896, "Base Facilities Environmental Quality"; Work Unit number 008B36, "Maneuver Disturbance Assessment Applied to Gopher Tortoises." The technical monitor was Mr. William Woodson, DAIM-ED.

The work was completed under the direction of the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Harold E. Balbach. Special thanks are given to Elizabeth Keane, CEERD-CN-N, who was of great assistance in preparing the final draft, especially the organization and formatting of the many tables in the appendices. The laboratory studies were performed by Mark Guelta in the facilities of the U.S. Army Research, Development and Engineering Command (RDECOM), Aberdeen Proving Ground, MD. The smoke penetration work was completed under Military Interagency Purchase Request No. W81EWF32325521 to RDECOM. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Steve Hodapp is the Threatened and Endangered Species Program Manager. Alan B. Anderson is Chief, CEERD-CN-N, and Michael Golish is Acting Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. The Acting Director of CERL is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Domestic Army installations, when combined with installations of other U.S. military services, total more than 25 million acres (about 10 million hectares). Among this land area are significant parcels in which the intensity of use is low enough, or infrequent enough, to allow the continuation of populations of species which, although originally common, are now much less common outside the installation than within it. Some of these species are designated as endangered or threatened under the Endangered Species Act of 1973 (Public Law 93-205; 16 U.S. Code 1531 et seq., as amended) (ESA). Other species are not yet so designated, but they are considered locally or regionally threatened or of special concern ("at risk"). Army installation managers are regularly called upon to accommodate the needs of such at risk species to the greatest degree possible without compromising the essential mission activities of the base.

One of these "species at risk" is the gopher tortoise (*Gopherus polyphemus*), a large, land-dwelling turtle that is or was found in parts of six southeastern states. The tortoise digs its burrows in sandy soils where the forest canopy is open enough to allow the sun to reach the surface. In the past, there was a strong association with pine forests, especially longleaf pine (*Pinus palustris*). With the advent of plantation forestry, as well as loss of habitat to urbanization, populations are declining throughout their range. One report (Auffenberg and Franz 1982) estimated that in the past 100 years gopher tortoise populations have declined by 80 percent. This significant decline resulted in the species being listed by the Fish and Wildlife Service (FWS) as "Threatened" in Louisiana, Mississippi, and west of the Tombigbee and Mobile Rivers in Alabama (*Federal Register*, July 7, 1987). The tortoise is being studied as a part of the Army Threatened and Endangered Species (TES) research program due to its potential for causing training conflicts at locations within the nonlisted (eastern) population were it to be listed, as was recommended by an advisory group in January 2003. At least 18 military bases are known to have gopher tortoises (Wilson et al. 1997).

A species listed as endangered throughout its range is the Indiana bat (*Myotis sodalis*) (*Federal Register*, March 11, 1967). The Indiana bat is a medium-sized bat whose diet consists of insects. Females and juveniles forage in the airspace near the

foliage of riparian and floodplain trees. Males forage the densely wooded area at tree-top height (LaVal et al. 1976, 1977). In summer, habitat consists of wooded or semiwooded areas, mainly along streams. Solitary females or small maternity colonies bear their offspring in hollow trees or under loose bark of living or dead trees (Garner and Gardner 1992, Humphrey et al. 1977). Dead trees are preferred roost sites (Humphrey et al. 1977) and trees standing in sunny openings are attractive because the air spaces and crevices under the bark are warmer. In a 2000 survey, nine Army installations reported that the Indiana bat was found on their property, and three other installations reported that the Indiana bat was known to be found on property contiguous to the Army lands. The great generalizations with which summer habitat is described means that, in theory, almost any hardwood forest near a body of water has potential to be used as summer habitat. This potential makes it difficult to firmly exclude the bat from concern across wide ranges of most of the eastern third of the United States.

Among the training activities that occur in or near both Indiana bat and gopher tortoise habitat is troop preparedness training and the field testing of generating equipment that releases fog oil smoke into the atmosphere. Obscurants have long been used to mask movements of troops and mechanized equipment. Of the conventional smokes, the white smoke generated from vaporization and condensation of liquid fog oil is an effective obscurant in the visible range. It is the most heavily used obscurant for troop training because of its low cost, ease of handling and smoke generation, dispersion characteristics, and safety (Eberhard et al. 1989).

SGF-2 fog oil (FO) is the obscurant used most frequently for military training. It is a middle distillate product of crude petroleum and is drawn from raw industrial lubricant oil. The FO procured by the U.S. military has undergone a modified refining process to reduce quantities of potentially harmful components. Although called a smoke because of its appearance when generated in the field, it is not burned but rather vaporized and disseminated by recondensation as the vapors cool in the air. Airborne FO droplets have a mass median aerodynamic diameter (MMAD) typically between 0.9 and 1.9 μm (Driver et al. 1993), a size range that deposits within the lung and air sacs of birds (Driver et al. 1990).

However, the effects of airborne fog oil on wildlife are poorly known, or unknown. This lack of definitive knowledge has resulted in an Army research focus on this topic for the past several years. It was originally determined to be important to examine potential adverse effects in birds because they are often more sensitive to airborne pollutants than mammals, have high public visibility, and are used as bioindicators of ecosystem health. This resulted in a series of studies that were a part of the Army TES research program (Getz et al. 1996). This research resulted in a series of technical reports examining the effects of fog oil smoke on various avian

species that served as surrogates for the endangered red-cockaded woodpecker (*Picoides borealis)* (Driver et al., 2002a, 2002b, 2004, 2005). Overall, the conclusion of this series of studies was that fog oil vapors posed little direct hazard to altricial avian species, including the red-cockaded woodpecker and other birds in the same general size class (ca 50 g body mass). One cannot extrapolate, however, from these studies to either the tortoise or the bat due to extremely great differences in metabolism and lung function between them and the birds studied.

Objective

Because it is not known whether fog oil smoke has any health effect on either the gopher tortoise or the Indiana bat, the first objective of this research program was to attempt to demonstrate, in a nonliving simulated environment, the degree to which fog oil smoke was able to penetrate into the living space of these species. With this knowledge in hand, a decision could be made about whether it was necessary to pursue further toxicological studies with either species to determine any actual health hazard related to exposure to fog oil smoke usage in Army training activities. In both cases, it would be assumed that animals on the ground surface (tortoises) or resting on the outer bark of trees (bats) would be exposed to ambient levels of the smoke. Bats in flight would, of course, also be exposed to ambient levels.

Scope

This study was limited to the measurement of the penetration of fog oil smoke into simulated burrows (for the gopher tortoise) and simulated maternal roost trees (for the Indiana bat). The "habitats" were constructed of corrugated plastic drainage pipe (for the gopher tortoise) or corrugated plastic drainage pipe combined with fiberboard concrete forms (for the Indiana bat). All studies took place in the wind tunnel facility of the Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD. No animals, living or dead, were involved at any time. The desert tortoise (*G. agassizii*) is a closely related tortoise whose habitat is in deserts of southwestern California and adjacent Nevada, Arizona, and Utah. Although not a focus of the present study, it is likely that some or all of the physical principles examined also would apply to that tortoise in its habitat.

Approach

In the case of the tortoise, the "habitat" evaluated was the burrow, a tunnel from 3 to 6 m or more long, which is dug into the soil, and descends at a moderate angle until it is 2 to 3 m below the surface. In the case of the bat, the particularly sensitive habitat setting was postulated to be a hollow tree, or snag, to which access had been gained through the decay of the base of a small (10 cm) branch. Two simulated habitats that closely approximated these two situations would be constructed. Fog oil smoke would be generated in a controlled, laboratory setting in which the concentration could be varied and the flow of smoke-laden air could be directed at or near the opening of the "habitat." Detailed measurements would be taken of the concentration of smoke at several locations within the simulated habitat, and these measurements would be compared to the ambient ("challenge") concentration within the tunnel at that time. Comparisons also would be made of the level of penetration experienced when the stream of smoke was directed across the habitat opening at different orientations and at different windspeeds.

Mode of Technology Transfer

The information included in this report is one portion of the materials prepared by the Engineer Research and Development Center to assist installation natural resources and threatened and endangered species program managers. The primary means of communicating the smoke penetration information will be through publication in the scientific literature, as well as through the availability of this report. The specific data presented are intended to be used in the preparation of biological assessments (BAs) and biological opinions (BOs) related to Army training activities in which either the gopher tortoise or the Indiana bat are present, and for endangered species management plans (ESMPs), integrated natural resources management plans (INRMPs), and in the preparation of ecological risk assessments involving training or equipment testing that uses fog oil smoke where either the tortoise or the bat are present.

This report will be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil

2 Background

Concerns over potential effects to TES from activities at U.S. Army training sites has sparked much debate, field study, and closure or limitations of activities on Army lands. Range managers often must balance the requirements of troop training exercises and equipment testing against the need to protect individual and/or populations of TES. The use of battlefield smokes for marking and screening represents a challenge in that the smokes not only affect the immediate area of application, but they also affect any areas down wind of the test site.

Testing and training sites can encompass large areas of relatively undisturbed open range and wooded areas. These sites have become valuable for existing and displaced animal species, including populations of TES. Therefore, the protection of these TES has fallen more under the stewardship of the Army than any other military service or public group. The ability to manage and make decisions regarding training and testing requirements versus TES stewardship requires insight into species habitat requirements, lifecycle, seasonality of testing and training, and effect of testing, if any, on the species of concern. Getz et al. (1996) conducted a preliminary assessment of the potential impact of fog oil smoke on selected TES. Part of their findings and recommendations included the testing of certain assumptions regarding the protection a nest cavity or underground burrow may afford its occupants. Specifically mentioned were the nests of the red-cockaded woodpecker (RCW), maternal colonies of the Indiana bat, and burrows of the gopher tortoise and desert tortoise. Several researchers since have studied the penetration of FO into RCW nest cavities (Driver et al. 2002b, Guelta and Checkai 2001), with the conclusion that, for practical purposes, the concentrations of fog oil obscurant inside the nest cavities are similar to ambient levels. There have been no studies relevant to tortoise burrows or bat maternal colonies.

The gopher tortoise has a current distribution in the southeast United States from southernmost South Carolina, through Georgia, west to extreme eastern Louisiana, and south throughout Florida. The gopher tortoise digs underground burrows in softer sandy soils that can extend up to 6 to 7 m or more in length. Other ground-dwelling animals also frequent these burrows. Generally, it has been thought that these burrows would provide the inhabitants with protection from exposure to smokes used at test and training sites. The general lack of test data to support ideas of any protection provided by the underground burrow has led to proposed testing of underground burrows. The greatest threat to the gopher tortoise is loss of

habitat. The gopher tortoise, therefore frequently is found on government lands, including Army testing and training sites. Wilson et al. (1997) reported active gopher tortoise burrows on 19 military testing and training sites throughout the southeastern United States. The gopher tortoise and many vertebrate species make use of the burrows for shelter from temperature extremes and predation. The gopher tortoise excavates burrows that are generally at least 5 m in length and of a diameter to allow them to turn around. A single tortoise may use several burrows simultaneously over its normal range, although females, especially, appear to have preferred burrows to which they return a majority of the time.

The Indiana bat has a home range that extends from the Ozark Plateau in Oklahoma, north to Iowa and southwestern Wisconsin, east to New Hampshire, and south to portions of Georgia and Alabama (Evans et al. 1998). They migrate seasonally from their summer range in northern closed canopy riparian forests to their winter hibernation areas in more southern limestone caves and abandoned mineshafts. Summer roosts generally are loose or heavily barked trees that provide daytime solar shelter. Maternity roosts, which are the critical focus of this study, may be on or within large standing dead trees, especially those found in the area of permanent streams or floodplain forests. Single male bats or maternity colonies may use several roosts sites or move frequently between primary and alternate roosts, depending on environmental conditions or disturbance. One must assume, based on the studies of RCW nest cavities (Driver et al. 2002b, Guelta and Checkai 2001), that bats resting on the exterior of trees, whether or not under flaps of bark, will be exposed to roughly ambient levels of obscurant. The question being examined here relates to the use of snags and broken or hollowed trunks by maternal colonies, primarily those of the Indiana bat, and what concentrations of obscurant may be expected within the cavity of these trees compared to ambient levels when smoke generation is taking place. Many other species of bats may use hollow trees for this purpose, either separately or concurrently with the Indiana bat. Any results of these simulations will be equally applicable to these species.

Generally, the collection of field data can prove challenging and costly. Site characteristics, uncooperative weather, and logistics of conducting fieldwork often greatly increase the costs and decrease the quality and completeness of data collected. The potential costs of conducting field tests can place desirable programs on a “back burner” until an impact to range use or testing has been realized. An alternative is to first conduct initial testing under the more controlled conditions of a laboratory or engineered study using models that closely imitate conditions that may be seen in the field. Decisions then may better be made to determine which elements need to be studied under field conditions.

This study is designed to gather initial data to assess the potential of penetration of the large-area screening smoke FO into a model burrow of the gopher tortoise and a model of a hollow standing tree cavity. During this study, models were constructed to closely approximate the geometry of burrows and cavities observed in the field. Fog oil smoke was generated at concentrations that are regularly used in field exercises and presented to the burrow entrance at wind speeds and orientations that represent field conditions. These conditions included three wind speeds from 4 to 12 mph; wind orientations of 0°, 90°, and 180°, and obscurant smoke concentrations from 50 to 300 mg/m^3.

3 Methods

Tortoise Burrow

The simulated tortoise burrow was constructed using corrugated 20-cm (8-in.) diameter plastic drainpipe and 20-cm (8-in.), diameter dryer vent hose. This diameter was selected as being reasonably close to the functional size of the burrow of a mature tortoise. Although it is recognized that the cross-section of a burrow is not round, the physical factors relating to air movement are believed to be similar enough to not significantly affect the measurements sought. The opening to the model burrow was fabricated using 6-mm (¼-in.) plywood, expanded metal screening, and plaster of Paris (Figure 1). The burrow opening was designed to simulate the depression made by a tortoise at the entrance to the burrow. The burrow of a desert tortoise is generally similar, although the burrow usually is shorter and less deep, thought to be a reflection of the fact that the desert soils often are stony and more difficult to excavate. The model used here also should be relevant to desert tortoise burrow smoke penetration potential.

The entrance to the burrow gradually sloped to approximately 10 cm (4 in.) below grade. The top of the burrow entrance was slightly below grade, with a mound of simulated dirt slightly above grade. This sculpted entrance was fastened to the first section of flexible duct. The duct was connected to a section of corrugated pipe so that the first sensor array was 1 m down the "burrow." Additional lengths of flexible duct alternated with sections of drainage pipe so that other sensors were placed at the 3-m and 5-m positions in the simulated burrow (Figure 2).

The entrance to the model burrow was constructed on a moveable platform that fit into a wind tunnel test section. The platform was movable to effect several 90° changes in FO air flow challenge orientation. The model burrow was 5 m in length. Aerosol sensors were placed just outside the entrance for challenge FO concentration measurement and 1, 3, and 5 m below the inside opening of the burrow.

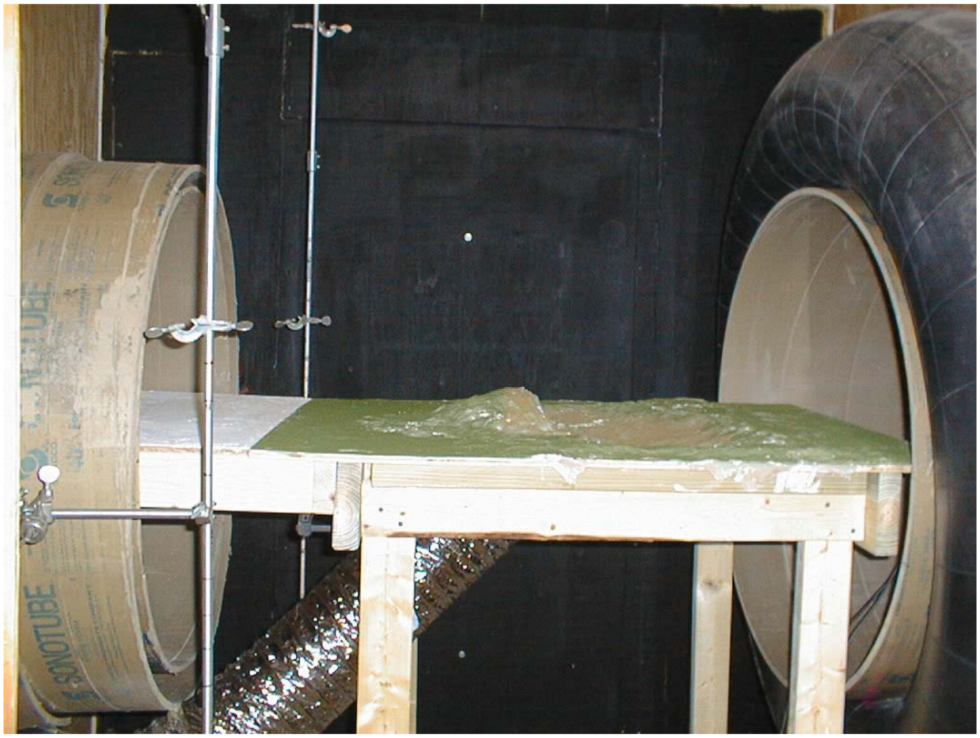

Figure 1. The model gopher tortoise burrow placed in wind tunnel test section with entrance oriented 180° to wind direction (i.e., away from the air flow).

Figure 2. The model gopher tortoise burrow extended through door of the wind tunnel test section with entrance facing 90° to wind direction.
Each section of black corrugated pipe contains an aerosol sensor. Those at the 3-m and 5-m positions are visible here. The 1-m position is within the chamber.

Tree Trunk Bat Colony Cavity

The hollow tree trunk model also was constructed from a 20-cm (8-in.) diameter corrugated plastic drainpipe (Figure 3). Aerosol sensors were mounted at the entrance to the model and at each end of the 2.25-m (88-in.) long model. The cavity wall was made to simulate a 1 ½-in. thick trunk by encasing the corrugated pipe in a 30-cm (12 in., nominal) fiber concrete forming tube. The inner cavity of the model was held in place by expanding foam and screws. Mounting screw heads, tube joints, and aerosol sensor access holes were sealed with expanding foam, silicon caulk, and duct tape. The spindle-shaped opening, approximately 7 cm wide and 25 cm high (Figure 4), was patterned on the shape of a decayed branch base that had created an opening into the interior of the "hollow tree," creating a setting for a maternal colony. Actual openings may be larger or smaller, or the hollow tree may be completely open to the air at its upper end. This opening was sized to reflect a moderate-size, realistic area for movement of bats as well as potential penetration of FO obscurant.

Figure 3. The inner section of the tree trunk cavity constructed of 20-cm (8-in.) drainpipe.

Figure 4. The entrance to the roost cavity cut through the outer shell of the tree trunk, the filler foam, and the hollow plastic pipe.

Generation of Fog Oil

Fog oil was generated using a pair of small scale smoke generators (S3-G). An S3-G is a gasoline-powered electric generator with a modified exhaust system (Figure 5). This type of small system was been developed for the multiple functions of FO generation and generation of portable power to allow for field operation of FO detection equipment, pumps, data loggers, and computer systems. In this study, this equipment was operated using internal electric power sources from the building, and the electric power was used to power a high-temperature heat tape, which assisted in vaporization of the FO and helped to keep the exhaust gas in the vaporization chamber above 400^{o}C.

The modified exhaust/vaporization chamber is comprised of a 3.4-cm (1 ½-in.) diameter by 54-cm (24-in.) long galvanized pipe. Ports in the end of the exhaust allow injection of FO and engine exhaust. The hot exhaust from the S3-G engine vaporizes the liquid FO and directs it into the wind tunnel inlet. The FO is pumped from a holding reservoir and injected into the vaporization chamber by a peristaltic pump. The variable speed of the pump allows control of the amount of FO generated and establishes the challenge FO concentration in the test chamber.

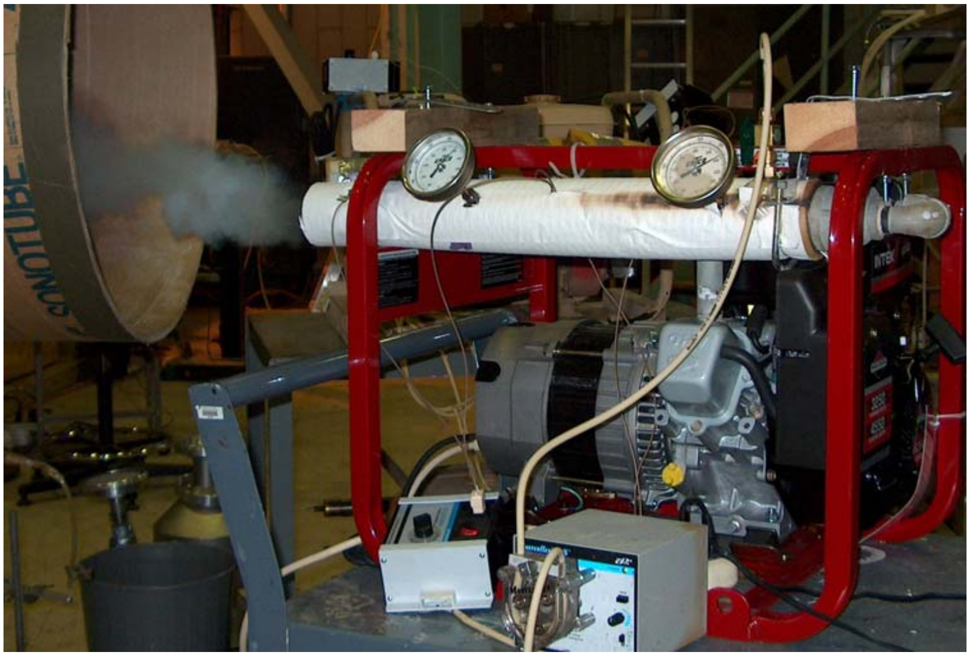

Figure 5. Small scale smoke generator (S3-G) was constructed from a portable gasoline powered electric generator.

Aerosol Wind Tunnel

The open-jet aerosol wind tunnel used for testing is operated by the Aerosol Sciences Team, Edgewood Chemical Biological Center, Research and Technology Directorate, of the U.S. Army Research, Development and Engineering Command (Figure 6). The open-jet aerosol wind tunnel test facility (the "OJ") is an open circuit, continuous flow, subsonic wind tunnel. It is particularly designed to conduct evaluations of aerosol collector inlets, but it is easily adapted to other aerodynamic test needs. It features a 1-m diameter open-jet test section, which eliminates wall effects and allows testing of large inlets or objects. The usable jet stream of moving air is then 1.0 m in diameter and 1.2 m long. This allows testing of most sizes of inlets in a velocity range of 4 to 25 mph. The test section area is enclosed by a large plenum approximately a 2.4-m (8-ft) cube at negative pressure with respect to atmosphere. This prevents aerosol leakage into the lab and provides a large area for viewing windows and lighting effects. This tunnel also is unique in its implementation of a "generic mixing system" (McFarland et al. 1999) upstream of the test section to assure good aerosol and flow profiles in the test section.

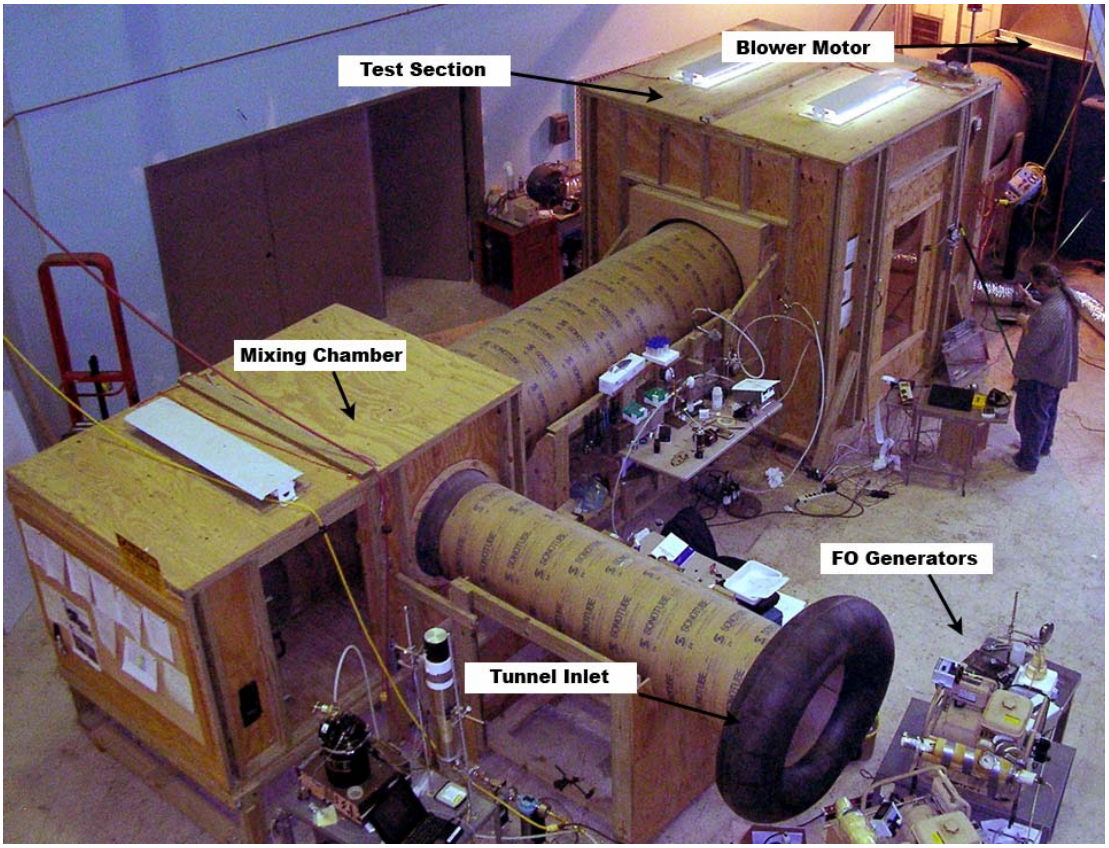

Figure 6. Open jet wind tunnel view from above.

Measurement of Fog Oil Smoke Concentrations

The FO challenge and penetration concentrations were measured using realtime aerosol sensors (RAS), model 2 (manufactured by Monitoring Instruments for the Environment [MIE] Inc., Billerica, MA). The sensors were calibrated prior to burrow testing using FO generated by the S3-G and concentrations measured using gravimetric analysis of open-faced filter samples.

The RAS is a compact airborne particulate concentration transducer with an operation principle based on the detection of scattered electromagnetic radiation in the near infrared. The RAS uses a pulsed GaALAs (gallium aluminum arsenide) light source, which generates a narrow-band emission centered at 880 nm. This source is operated at an average output power of about 5 mW. The radiation scattered by the airborne particles is sensed over an angular range of approximately 45° to 95° from the forward direction by a silicon-photovoltaic hybrid detector with internal low-noise preamplification. An optical interference-type filter is incorporated to screen out any light whose wavelength differs from that of the source.

Air surrounding the RAS passes freely through an open-ended sensing chamber. The RAS requires no pump for operation. The scattering sensing parameters have been designed for preferential response to particles in the 0.1 to 10 um size range. The RAS provides an analog output directly proportional to the concentration of airborne particles. The RAS is manufactured in two concentration ranges. The sensors used for this study have a dynamic range of 0.1 to 1000 mg/m3. Output gain for each of the four remote air sensors was set to 50 mV using a standard scattering window prior to calibration. The RAS used during this study were calibrated simultaneously using fiber filters sampled at isokenetic flow rates. Calibration equations were calculated for each RAS and used to quantify FO concentrations measured throughout the study.

Access holes just large enough to allow mounting of the aerosol sensors were cut into the corrugated drainpipe. The sensors were positioned so that the sensing volume of the aerosol sensor was as close to the center of the model burrow as possible (Figure 7). The access hole then was sealed to prevent airflow. Sensors were placed at distances of 1, 3, and 5 m from the simulated burrow mouth. The end of the model burrow farthest from the inlet (at the 5-m location) was closed with an endcap and sealed with expanding foam, mimicking the end of the burrow (Figure 2).

Figure 7. RAS mounted in plastic drain pipe mounted at end of model gopher tortoise burrow.

Particle size analysis was performed using an 8-stage, nonviable Anderson Cascade impact sampler, Model Mark II. Smoke was sampled with the impactor during calibration of the RAS. The FO generator exhaust temperature at the time of generation was 400°C.

Data Collection

Concentration data from the RAS were collected and saved using an Omega OM-500, multichannel data logger. The OM-500 logs analog out data as millivolts on as many as 5 channels. The OM-500 is a portable unit with battery pack for field operation. Data recorded by the OM-500 were downloaded to its accompanying software after each test run. The software allows for simultaneous display of up to five data sets, an example of which is shown in Figure 8. In this example, the traces from sensors 1 through 4 are shown in different colors. This example is taken from the simulated bat colony tree study. Data for all test results were entered into an Excel spreadsheet for manipulation and analysis.

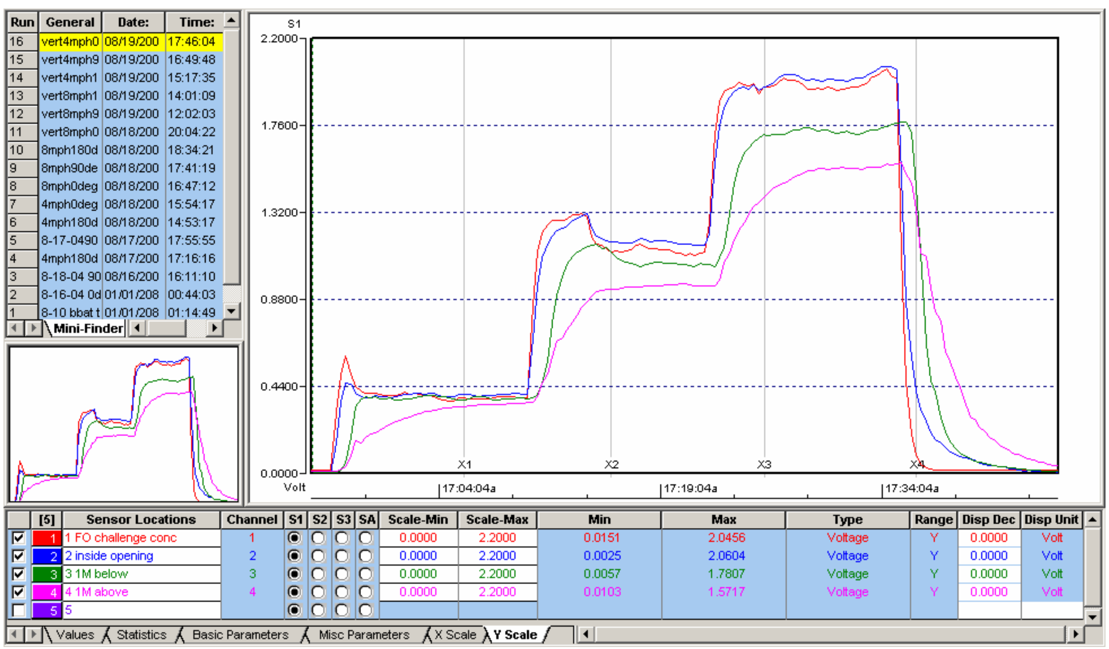

Figure 8. Example screenshot from Omega 5 data logging software.

Displaying output from four RAS from a test (4 mph, 0 degrees, vertical, and model tree trunk) showing tests at three successive concentrations.

Fog Oil

The FO used in this study was taken from local inventory at Aberdeen Proving Ground. Identification of FO used was taken from a 55-gallon drum label, as follows:

9150-00-261-7895	National Stock Number
CAGE/Prime 0A9L8	"Commercial And Government Entity"/Contractor ID number
Fog Oil 1DR Net Wt. 413 lbs.	
M 10 08/03 MFD 08/03	Manufactured date August 2003
Test and Re-inspect 08/06	Shelf life 3yrs, re-test in August 06
MIL-PRF-12070F	Military performance specification number
Flash Pt. 333OF, 167OC	
Boiling Pt. 621OF, 327OC	
Lot. D2163	
SP0450-98-D-4153-0340	Contract number from FY98
HOC Industries Inc.	
3511 N. Ohio, Wichita, KS 67219-3721	

Test Matrix

The test design for each of the models was to expose each to three concentrations of FO, using three different wind speeds at three orientations to wind direction, similar to the example shown in Figure 8. Each model would be put through 27 test series (Table 1). After testing of the model tortoise burrow, and prior to testing the model tree trunk cavity, concern was raised over potential settling effects due to gravity within a vertically positioned trunk model. The test matrix was changed to include vertical and horizontal positioning of the model tree cavity. Those test matrices are given in Table 2.

Table 1. Matrix of FO challenge testing for simulated tortoise burrow.

Wind speed (mph)	FO concentrations (mg/M^3)	Orientations (degrees to direction)	Tests (count)
4	50, 150, 300	0, 90, 180	9
8	50, 150, 300	0, 90, 180	9
12	50, 150, 300	0, 90, 180	9
Total tests			27

Table 2. Matrix of FO challenge testing for model tree trunk cavity.

Wind speed (mph)	Concentrations vertical position (mg/M^3)	Concentrations horizontal position (mg/M^3)	Orientations (degrees to direction)	Tests (count)
4	50, 150, 300	50, 150, 300	0, 90, 180	18
8	50, 150	50, 150	0, 90, 180	12
Total tests				30

4 Results

RAS Equipment Calibration

The four aerosol sensors used in this study were calibrated simultaneously by recording RAS output, separately from each sensor in millivolts versus weight of FO collected on glass fiber filters. Calibration equations were determined by linear regression of recorded data. Calibration data are displayed in Figures 9 through 12. RAS-1 was used throughout the study to record challenge FO concentration. "Challenge" in this usage and in the tables and graphs in this report refers to the concentration in the chamber outside the model during the test.

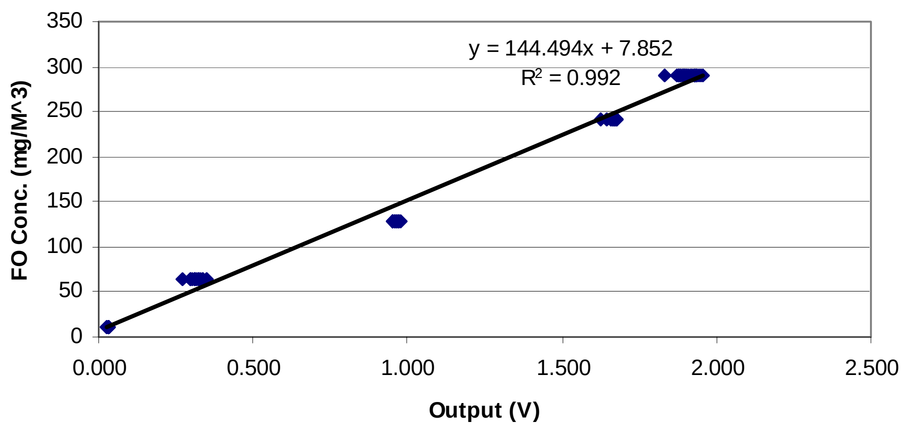

Figure 9. Linear regression calibration of RAS-1.

RAS-2 was used throughout the study to measure FO concentration 1 m inside the model gopher tortoise burrow or just inside the model tree trunk nest cavity.

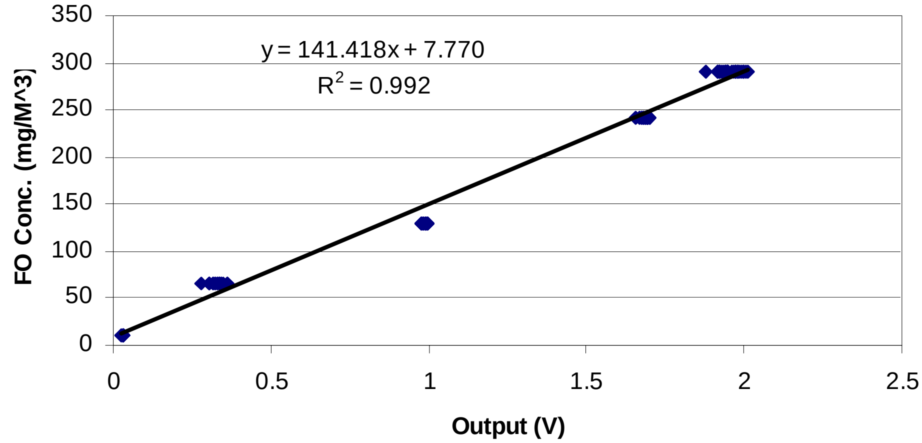

Figure 10. Linear regression calibration of RAS-2.

RAS-3 was used to measure FO penetration concentrations in the model gopher tortoise burrow at the point 3 m into the model burrow or in the model tree cavity 1 m left of or 1 m below the entrance.

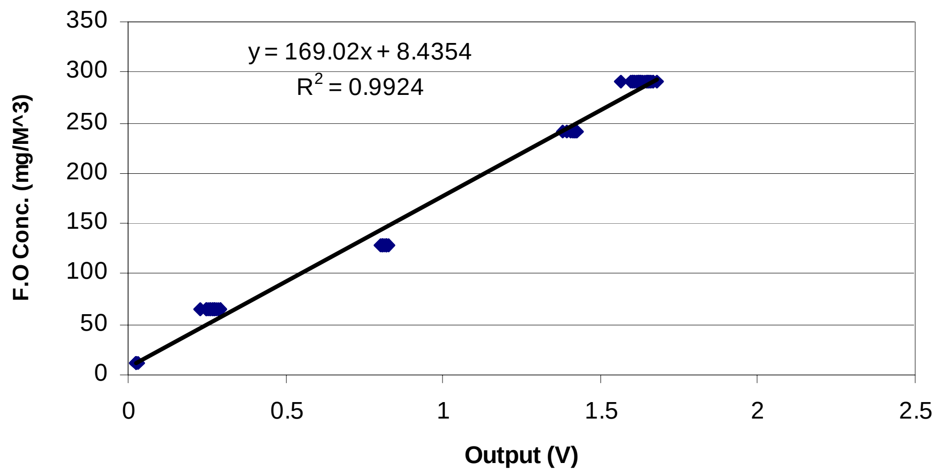

Figure 11. Linear regression calibration of RAS-3.

RAS-4 was used to measure FO penetration concentrations in the model gopher tortoise burrow at the point 5 m into the model burrow or in the model tree trunk cavity 1 m right of the entrance or 1 m above the entrance.

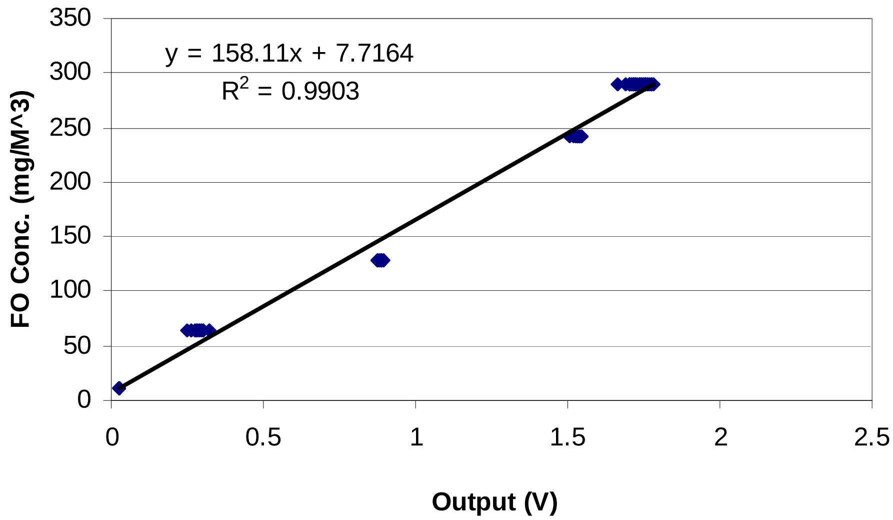

Figure 12. Linear regression calibration of RAS-4.

Challenge FO particle aerodynamic mass mean diameter was measured at 0.58 microns (Figure 13). This particle size falls in the lower range of FO particle sizes reported by Chester 1998, but it is realistic for a freshly generated smoke that was produced at a lower initial plume concentrations. Data were entered into an Excel spreadsheet, a best fit trend line was added by the program. Figure 13 is a cumulative plot of particle size distribution within the Andersen sampler.

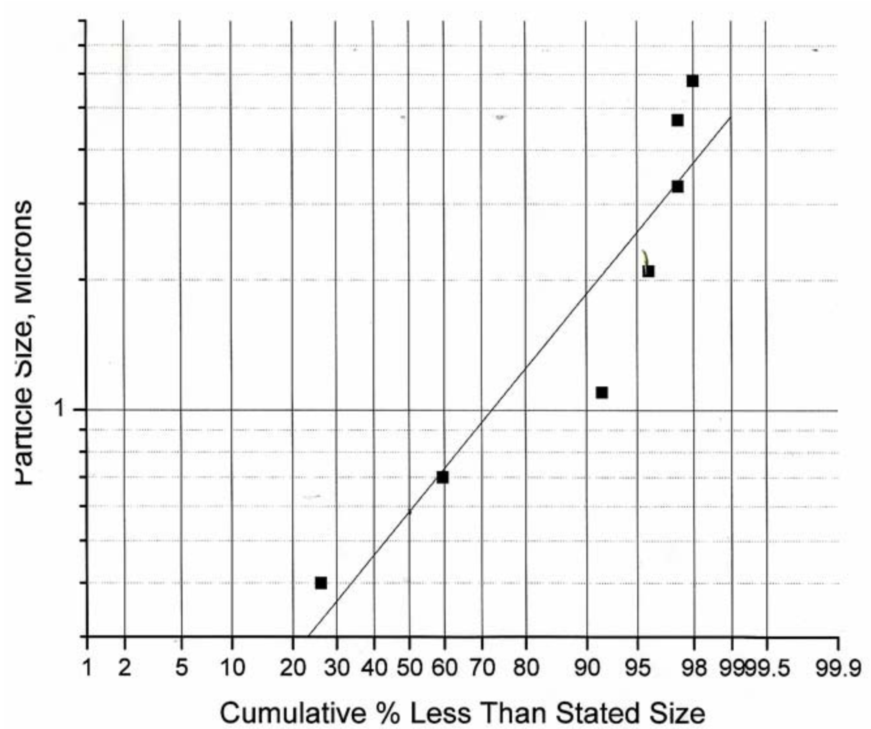

Figure 13. Anderson sampler plot of fog oil particle size distribution.

Model Tortoise Burrow Data

Fog oil penetration into the model tortoise burrow was minimal for all tests conducted. Table 3 is a summary of the average FO challenge and penetration concentrations measured. Data for model burrow concentrations are displayed only for the 1 m (into the burrow) sensor position. RAS-3 and 4 measurements at positions 3 m and 5 m into the burrow were below detectable levels (less than 1/10,000 of the ambient/challenge concentration) for the entire study and are not presented here. Appendix A presents the specific results for each of the 27 test sequences conducted to examine smoke penetration of the simulated tortoise burrow.

Table 3. Summaries of mean FO challenge and penetration concentrations measured during testing of the model gopher tortoise burrow.

	Orientation – 0 degrees		**Orientation – 90 degrees**		**Orientation – 180 degrees**	
Wind Speed (mph)	Challenge Conc. (mg/M^3)	FO Penetration 1 m inside (mg/M^3)	Challenge Conc. (mg/M^3)	FO Penetration 1 inside (mg/M^3)	Challenge Conc. (mg/M^3)	FO Penetration 1 inside (mg/M^3)
4	50.3	0.0	52.4	0.0	51.1	0.0
4	152.4	0.0	152.4	0.1	153.6	0.0
4	305.0	0.0	301.6	0.3	296.2	0.3
8	51.1	0.0	51.4	0.0	51.3	0.0
8	153.4	0.0	152.5	0.1	161.2	0.1
8	304.0	0.0	299.0	0.4	304.7	0.1
12	51.1	0.0	50.8	0.0	51.7	0.0
12	153.2	0.0	152.4	0.2	164.3	0.0
12	265.6	0.1	281.9	0.3	240.8	0.0

Model Tree Cavity Data, Horizontal Position

The FO challenge to the model tree trunk cavity was performed with the model first in a horizontal position, with the length of the model perpendicular to the direction of the challenge air stream (see Figure 2). One might ask, "Why place a simulated tree trunk horizontally?" The reason relates to a limitation of the largest dimension of the aerosol test chamber, approximately 2.4 m (8 ft) (see Figure 6). It was determined that, were it necessary to test a model longer than 2.4 m, it would be possible to modify the chamber to allow testing of a longer model only in a horizontal position. Initial tests were performed in this position. If initial results found significant smoke penetration to the 1 m right and left sensors, tests of a longer model were deemed unnecessary (i.e., that the interior had been fully compromised). Also, had there been no penetration to the 1 m point, the assumption was that there would have been no penetration to greater distances. Testing included challenging the model to 3 concentrations of FO at the 4 mph wind speed and two concentrations of FO at the 8 mph wind speed as described for Table 2.

Location of the aerosol detectors are described as "challenge," "entrance," for the RAS just behind the model cavity opening, and 1 m right or left for the RAS located at either end of the cavity in the horizontal position. The RAS at location 1 m right is the right end of the model when facing the cavity opening at 0° orientation to the challenge FO.

In distinct contrast to the insignificant degree of smoke penetration of the simulated tortoise burrow, there was significant penetration into the interior of the simulated hollow tree (Table 4). With the orientation at 0° (i.e., with the opening facing into the airstream) interior concentrations equaled or exceeded the ambient (challenge) levels. Interior concentrations at other orientations are much less, and animals within trees with openings facing away from the generator equipment (and wind experienced during the exercise) could expect less exposure, perhaps 10 to 30 percent of ambient (Table 4). Appendix B presents the specific results for each of the 15 test sequences conducted to examine smoke penetration of the simulated hollow tree in a horizontal orientation.

Table 4. Summary of average fog oil penetration into the model tree trunk cavity for each test with model in the horizontal position.

Wind speed	Orientation (degrees)	FO Challenge concentration (mg/M3)	% penetration		
			entrance	1 m left	1 m right
4MPH	0	51	105	111	88
4MPH	0	193	107	113	100
4MPH	0	282	111	115	102
4MPH	90	52	18	21	20
4MPH	90	173	9	12	7
4MPH	90	310	9	9	8
4MPH	180	99	36	14	13
4MPH	180	172	35	11	17
4MPH	180	300	35	10	26
8MPH	0	54	104	106	92
8MPH	0	208	105	107	85
8MPH	90	67	15	17	15
8MPH	90	260	8	9	7
8MPH	180	63	33	19	20
8MPH	180	246	29	10	13

Model Tree Trunk Data, Vertical Position

For this series of tests, the "trunk" of the simulated hollow tree was reoriented within the test chamber until it was vertical, the former "right" leg becoming the upper axis. This was done to determine if there would be measurable differences in interior concentration between the pair of RAS sensors that now were located 1 m above and 1 m below the opening in the cylinder, as opposed to 1 m right and left of the opening, as in the previous series. Essentially, the potential issue was, "Does

gravity play any role in the distribution of obscurant smoke within the interior of the form?" Table 5 summarizes the results of the series of studies using the model cavity tree oriented vertically. Although not statistically highly significant, a trend seems to be visible, especially at lower windspeeds, when the cavity is at 0° (i.e., when the airstream is moving directly into the opening). The sensor (RAS-3) which is placed 1m below the entrance consistently showed concentrations 20 percent or more greater than the sensor placed 1 m above the entrance (see also Figure 8, which shows the 4 mph, 0° test series). This pattern is less consistent at higher wind speeds and not discernable for other orientations. Appendix C presents the specific results for each of the 15 test sequences conducted to examine penetration of the simulated hollow tree in vertical orientation.

Table 5. Summary of average fog oil penetration into the model tree trunk cavity for each test with model in the vertical position.

Wind speed	Orientation (degrees)	FO Challenge concentration (mg/M3)	% Penetration		
			entrance	1 m below	1 m above
4MPH	0	64	99	114	87
4MPH	0	177	100	107	85
4MPH	0	293	99	102	83
4MPH	90	64	15	18	15
4MPH	90	171	9	10	7
4MPH	90	293	7	8	6
4MPH	180	57	34	21	28
4MPH	180	178	31	11	24
4MPH	180	300	42	10	34
8MPH	0	61	109	109	82
8MPH	0	241	99	101	84
8MPH	90	60	16	18	16
8MPH	90	246	7	8	6
8MPH	180	48	32	22	21
8MPH	180	234	23	10	15

5 Conclusions and Recommendations

Upon examination of the data presented in Table 3 and Appendix A, it must be concluded that it is improbable for significant concentrations of fog oil smoke in tortoise burrows to result from smoke generating activities on Army training and testing lands. Under the most taxing conditions (i.e., with the airstream blowing directly toward the mouth of the simulated burrow), the smoke concentrations were approximately 0.01 percent (less than 1/1000) of the ambient level, they never exceeded 0.75 percent, and were lower with other burrow mouth orientations.

The conclusion must be that it is not necessary — in further conduct of Army research into potential threats to threatened, endangered, and at-risk species — to conduct field studies of fog oil smoke within tortoise burrows. Both gopher and desert tortoises, however, spend considerable time on the surface while feeding and moving about their habitat during social interaction with other tortoises. During these periods they would, of course, be exposed to approximately the full concentration of smoke. Should it become necessary to do so, further studies of the effects of fog oil smoke on the tortoises themselves may be required. However, measurements of concentrations within burrows may reasonably be assumed to be very low, approaching zero, and could not represent a significant health threat.

Conclusions for the simulated hollow tree cavity are quite different. Examination of the data in Tables 4 and 5, and the more detailed data in Appendices B and C, may be interpreted to show that concentrations within the tree cavities are not significantly different from the ambient levels. Thus, no significant degree of protection is likely to be afforded to members of a maternal colony of the Indiana bat or of other species using this habitat. As noted in the introduction, previous studies relating to the penetration of fog oil smoke into nest cavities of the red-cockaded woodpecker (Driver et al., 2002b, Guelta and Checkai 2001), found that penetration ranged from 60 to +80 percent of the ambient level. The larger opening of the present cavity tree model suggested that penetration was likely to be high, and this was borne out in the results. Thus, if further examination of the potential for fog oil smoke to affect the health of the Indiana bat, or other bat species, is conducted, no level of protection for individuals inside the tree cavity should be assumed. When and if risk assessments are prepared, this should be taken into account in the calculations.

References

Auffenberg, W., and R. Franz. 1982. The status and distribution of the gopher tortoise (*Gopherus polyphemus*). R. B. Bury (ed.) *North American Tortoise: Conservation and Ecology*. U.S. Fish and Wildlife Service, Wildlife Research Report 12, pp. 95-126.

Chester, Nancy A. 1998. *Review of Selected Army-Funded Research on Fog Oil Smoke Characteristics as Related to Clean Air Issues.* ERDEC-TR-475, Edgewood Research Development and Engineering Center, Aberdeen Proving Ground, MD.

Driver, C. J., L. G. Smith, J. K. Briant, A. E. Jarrell, A. Fairbrother, and P. Bucholz. 1990. "Respiratory exposure of avian wildlife to airborne microbial pest control agents: assessment methodologies," in *Review of Progress in Biotechnology Microbial Pest Control Agent Risk Assessment Program*. EPA 160010 901029, Office of Research and Development, U.S. Environmental Protection Agency.

Driver, C. J., M. W. Ligotke, J. L. Downs, B. L. Tiller, T. M. Poston, E. B. Moore, Jr., and D. A. Cataldo. 1993. *Environmental and Health Effects Review for Obscurant Fog Oil*. ERDEC CR 071, U.S. Army Chemical and Biological Defense Agency, Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD.

Driver, C. J., M. W. Ligotke, H. Galloway-Gorby, G. Dennis, K. A. Reinbold, and H. E. Balbach. 2002a. *Acute Inhalation Toxicity of Fog Oil Smoke in the Red-winged Blackbird, a Size-specific Inhalation Surrogate for the Red-cockaded Woodpecker*. ERDC/CERL TR-02-6, Engineer Research and Development Center/Construction Engineering Research Laboratory, Champaign, IL.

Driver, C. J., J. Ollero, Y. Fong Su, R. Fulton, G. Dennis, B. Tiller, H. Balbach, and K. Reinbold. 2002b. *Effects of Fog Oil Smoke on the Hatchability and Fledgling Survival of the House Sparrow (Passer domesticus), a Nestling Surrogate for the Red-cockaded Woodpecker.* ERDC/CERL TR-02-34, Engineer Research and Development Center/Construction Engineering Research Laboratory, Champaign, IL.

Driver, C. J., A. Jarrell, J. Ollero, G. Tiller, R. Fulton, B. Dennis, H. Balbach, and K. Reinbold. 2004. *Effects of Fog Oil Smoke on Immune Responses in the House Sparrow* (*Passer domesticus*) *and Red-winged Blackbird* (*Agelaius phoeniceus*). ERDC/CERL TR-04-13, Engineer Research and Development Center/Construction Engineering Research Laboratory, Champaign, IL.

Driver, C., R. Fulton, J. Ollero, M. Clark, G. Dennis, B. Tiller, and H. E. Balbach. 2005. *Inhalation Toxicity of Cogenerated Graphite Flake and Fog Oil Smoke in the Brown-headed Cowbird and the Red-winged Blackbird, Size-specific Inhalation Surrogates for the Red-cockaded Woodpecker*. ERDC/CERL TR-05-5, Engineer Research and Development Center/Construction Engineering Research Laboratory, Champaign, IL.

Eberhard, W. L., R. E. Cupp, and N. L. Abshire. 1989. "Conservation properties of oil fog used as an atmospheric tracer," *Atmos. Environ*, 23(8):1855-1861.

Endangered Species Act (ESA), Public Law 93-205, 16 U.S. Code 1531 et seq., as amended.

Evans, D. E., Mitchell, W. A., and Fischer, R. A. 1998. *Species profile: Indiana bat (Myotis sodalis) on military installations in the southeastern United States.* SERDP-98-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Federal Register. July 7, 1987; March 11, 1967.

Garner, J. D., and J. E. Gardner. 1992. *Determination of Summer Distribution And Habitat Utilization of The Indiana Bat (Myotis sodalis) In Illinois*. Illinois Department of Conservation, Final Report, Project E-3, Springfield, IL.

Getz, L. L., K. A. Reinbold, D. J. Tazik, T. J. Hayden, and D. M. Cassels. 1996. *Preliminary Assessment of the Potential Impact of Fog-Oil Smoke on Selected Threatened and Endangered Species*. TR-96/38, ADA306219. Construction Engineering Research Laboratory, Champaign, IL.

Guelta, M. A., and R. T. Checkai. 2001. *Methodology for Measurement of Fog Oil Smoke Penetration into a Red-cockaded Woodpecker Nest Cavity*. Report Number ECBC-TR 152, Edgewood Chemical Biological Center, U.S. Army Soldier and Biological Chemical Command, Aberdeen Proving Ground, MD.

Humphrey, S. R., A. R. Richter, and J. B. Cope. 1977. "Summer habitat and ecology of the endangered Indiana bat, *Myotis sodalist*." *J. Mammology* 58:334-346.

LaVal, R. K., R. L. Clawson, W. Caire, L. R. Wingate, and M. L. LaVal. 1976. *An Evaluation of the Status of Myotine Bats in the Proposed Meramec Park and Union Lake Project Areas, Missouri*. School of Forestry, Fisheries and Wildlife, University of Missouri, Columbia, MO.

LaVal, R. K., R. L. Clawson, M. L. LaVal, and W. Caire. 1977. "Foraging Behavior and Nocturnal Activity Patterns of Missouri Bats, With Emphasis on the Endangered Species *Myotis grisescens* and *Myotis sodalis*." *J. Mammal*, 58:592-599.

McFarland A. R., N. K. Anand, C. A. Ortiz, R. Gupta, S. Chandra, and A. P. McManigle. 1999. "A generic mixing system for achieving conditions suitable for single point representative effluent air sampling." *Health Phys.*76:17-26.

Wilson, D. S., H. R. Mushinsky, and R. A. Fisher. 1997. *Species Profile: Gopher Tortoise (Gopherus polyphemus) on military installations in the southeastern United States*, TR SERDP-97-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Appendices

Appendices A, B, and C contain the detailed results of the experimental generation of fog oil smoke and the measurement of the degree to which it penetrated the simulated living spaces of the tortoise and the bat. Each appendix consists of a series of tables showing the actual concentrations of fog oil used during the test series at each orientation of the test habitat to the moving air stream, and each tested concentration of fog oil aerosol. The table is followed by a graph showing the record of aerosol concentrations during the test periods. Note that maintaining any particular nominal test concentration was difficult, and not always achieved. Some fluctuations are visible in all graphs. Also, the nominal concentration could not always be achieved or maintained, especially at 300 mg/m^3, at which slightly lower levels were often the best that could be maintained by the equipment under prevailing temperature conditions. This variation probably does not affect the significance of the tests, because the relative results are so clear that variations of 10 percent (as in 265 mg/m^3 vs. 300 mg/m^3) could not possibly change the interpretations.

Appendix A: Data from Simulated Tortoise Burrow

Table A-1. Measured FO concentrations and calculated descriptive statistics during FO challenge of model gopher tortoise burrow at 4 MPH for 3 orientations and 3 concentrations.

	0 Degrees		90 Degrees		180 Degrees	
Calculated Parameter	Challenge (mg/M^3)	1 Meter (mg/M^3)	Challenge (mg/M^3)	1 Meter (mg/M^3)	Challenge (mg/M^3)	1 meter (mg/M^3)
Mean	50.25	0.01	52.45	0.02	51.05	0.00
min	48.79	0.00	48.45	0.00	47.50	0.00
max	53.12	0.03	57.08	0.06	55.17	0.00
median	50.17	0.01	52.58	0.01	51.29	0.00
std-d	0.85	0.01	1.65	0.01	1.79	0.00
count	82.00	82.00	78.00	78.00	80.00	80.00
Mean	152.40	0.02	152.42	0.14	153.55	0.00
min	138.40	0.01	147.90	0.10	125.92	0.00
max	159.46	0.03	159.40	0.19	164.04	0.00
median	152.30	0.03	152.33	0.15	154.46	0.00
std-d	3.30	0.01	2.29	0.02	6.51	0.00
count	84.00	84.00	80.00	80.00	123.00	123.00
Mean	305.04	0.03	301.60	0.35	296.20	0.28
min	300.12	0.01	287.26	0.25	275.61	-0.04
max	314.89	0.04	325.46	0.45	320.74	0.60
median	305.05	0.03	300.63	0.35	298.69	0.25
std-d	2.58	0.01	7.15	0.05	10.83	0.13
count	81.00	81.00	100.00	100.00	91.00	91.00

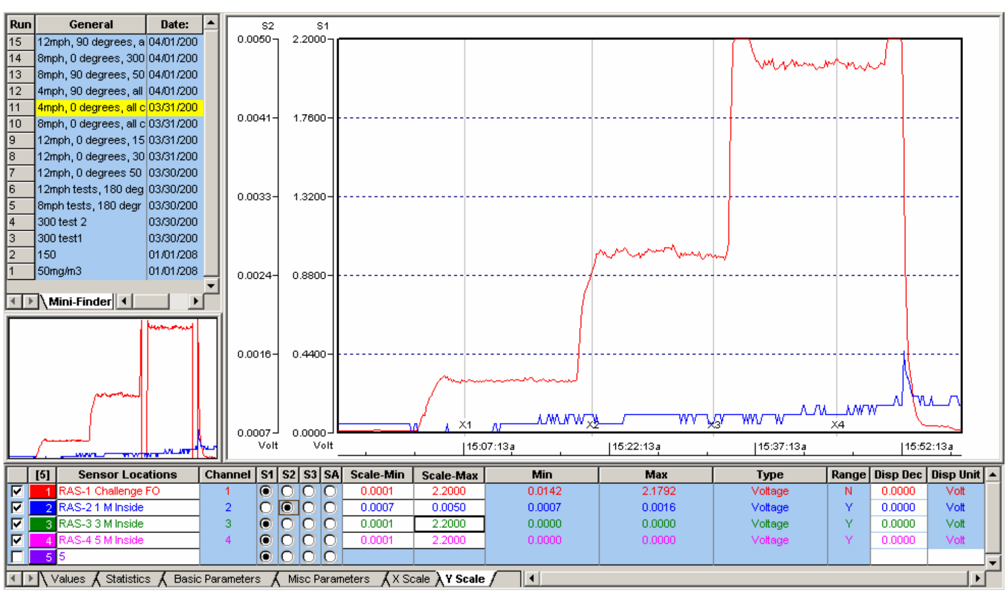

Figure A-1. FO concentration profile for model gopher tortoise burrow testing at 4 MPH, O degrees, 3 concentrations.

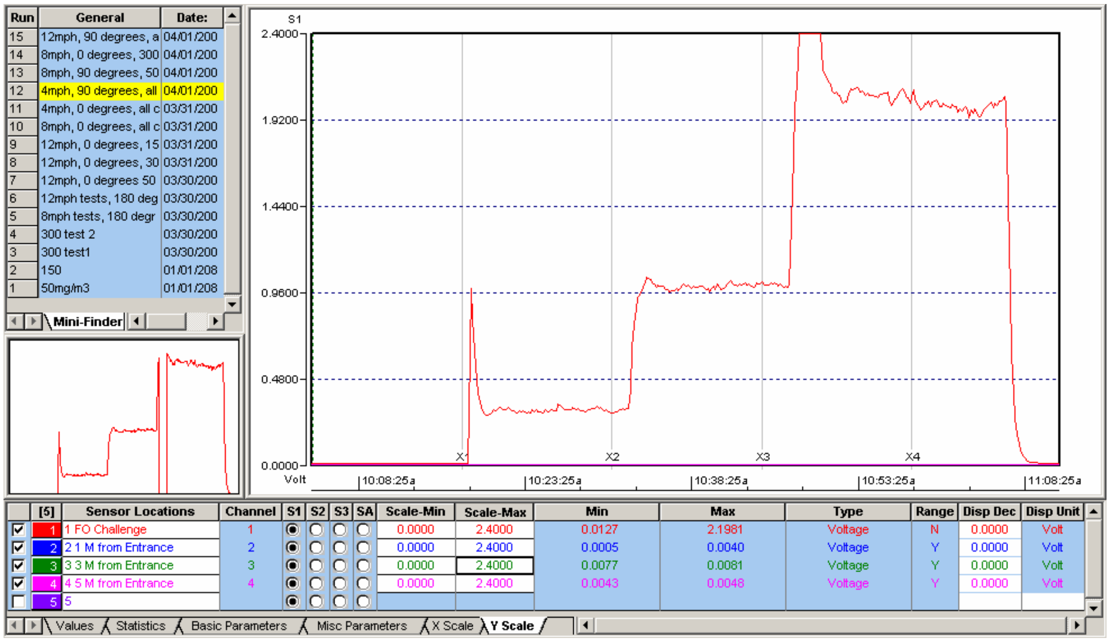

Figure A-2. FO concentration profile for model gopher tortoise burrow testing at 4 MPH, 9O degrees, 3 concentrations.

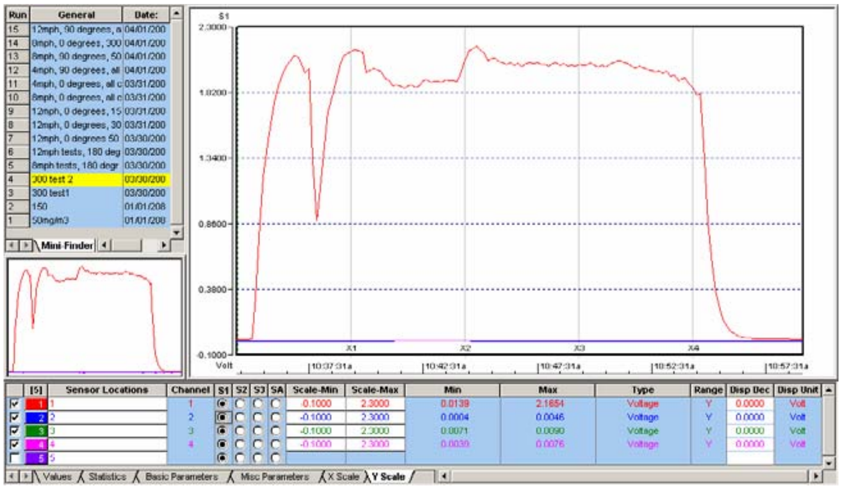

Figure A-3a. FO concentration profile for model tortoise burrow testing at 4 MPH, 18O Degrees (300 mg/m^3).

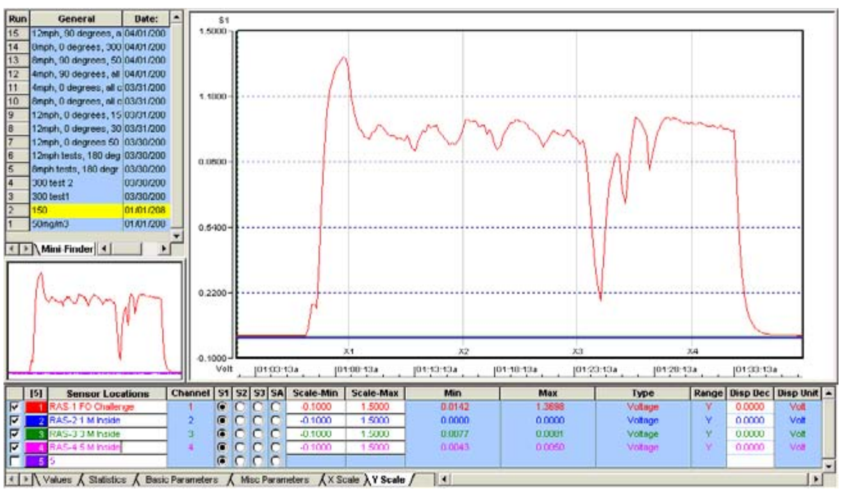

Figure A-3b. FO concentration profile for model tortoise burrow testing at 4 MPH, 18O Degrees (150 mg/m^3).

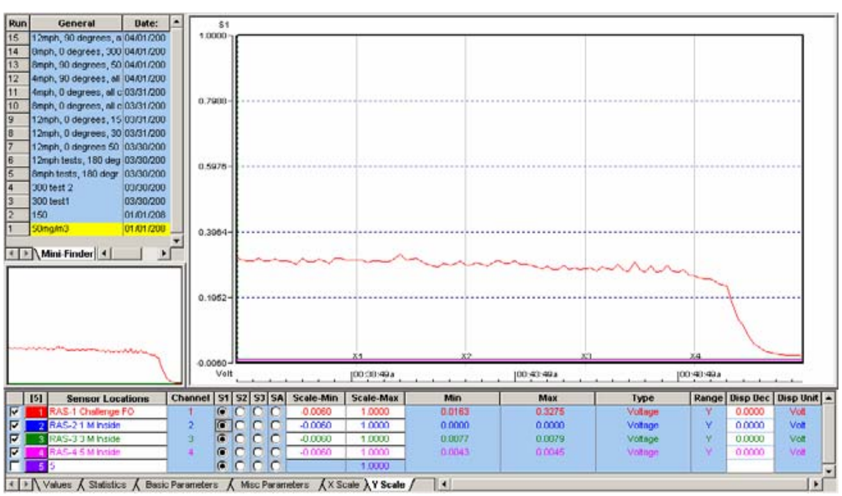

Figure A-3c. FO Concentration Profile for Model Tortoise Burrow Testing at 4 MPH, 18O Degrees (50 mg/m^3).

Table A-2. Measured FO concentrations and calculated descriptive statistics during FO challenge of model gopher tortoise burrow at 8 MPH for 3 orientations and 3 concentrations.

Calculated Parameter	0 Degrees Challenge (mg/M^3)	0 Degrees 1 meter (mg/M^3)	90 Degrees Challenge (mg/M^3)	90 Degrees 1 meter (mg/M^3)	180 Degrees Challenge (mg/M^3)	180 Degrees 1 meter (mg/M^3)
Mean	51.09	0.02	51.41	0.02	51.26	0.02
min	43.12	0.01	48.02	0.00	45.96	0.01
max	60.81	0.04	53.48	0.04	54.94	0.04
median	51.65	0.01	51.45	0.01	51.22	0.03
std-d	4.58	0.01	0.99	0.01	1.65	0.01
count	37.00	37.00	76.00	76.00	78.00	78.00
Mean	153.37	0.05	152.47	0.15	161.15	0.05
min	148.17	0.01	147.94	0.13	139.51	0.01
max	159.18	0.10	161.46	0.19	170.39	0.09
median	153.11	0.04	151.81	0.15	162.20	0.06
std-d	2.37	0.02	2.79	0.01	5.26	0.02
count	73.00	73.00	88.00	88.00	89.00	89.00
Mean	304.00	0.03	298.96	0.43	304.70	0.07
min	284.88	-0.01	263.12	0.31	289.64	0.03
max	325.07	0.77	323.79	0.58	311.82	0.10
median	303.69	0.01	309.51	0.41	305.95	0.09
std-d	4.39	0.03	19.74	0.08	4.90	0.02
count	85.00	85.00	88.00	88.00	68.00	60.00

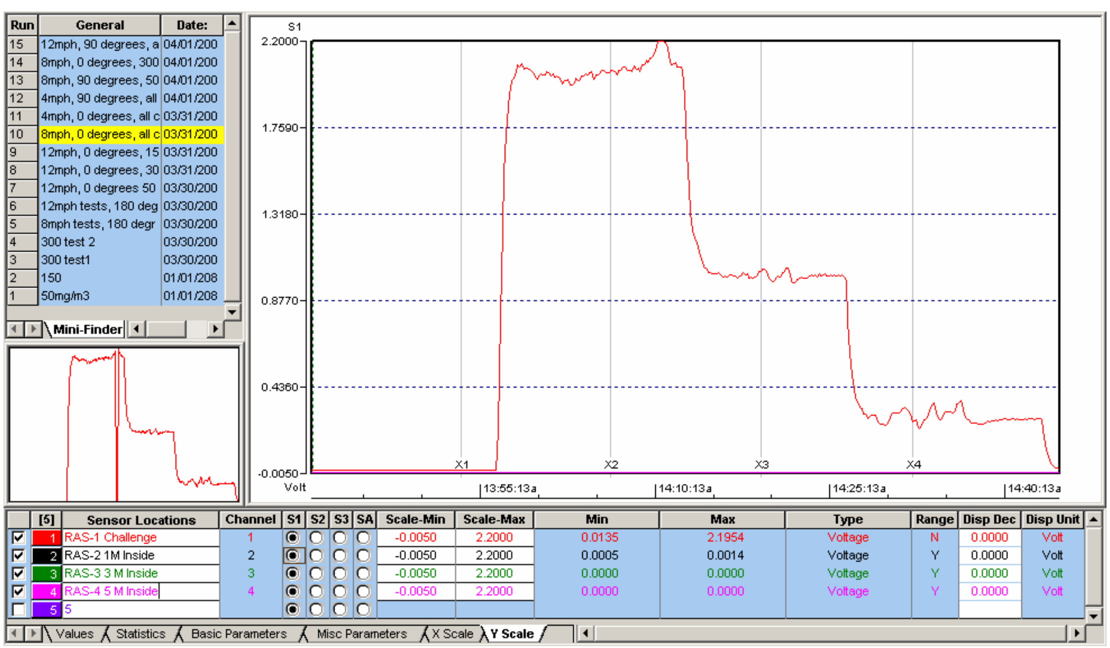

Figure A-4. FO concentration profile for model gopher tortoise burrow testing at 8 MPH, O degrees, 3 concentrations.

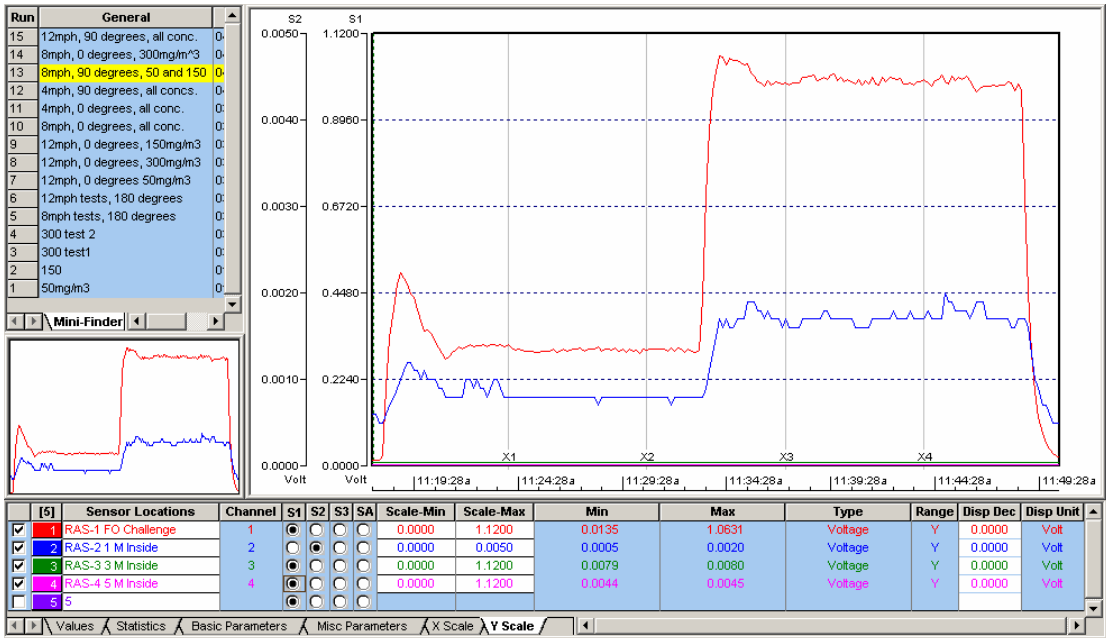

Figure A-5a. FO concentration profile for model gopher tortoise burrow testing at 8 MPH, 9O degrees, 2 Concentrations (50 mg/m^3 and 150 mg/ m^3).

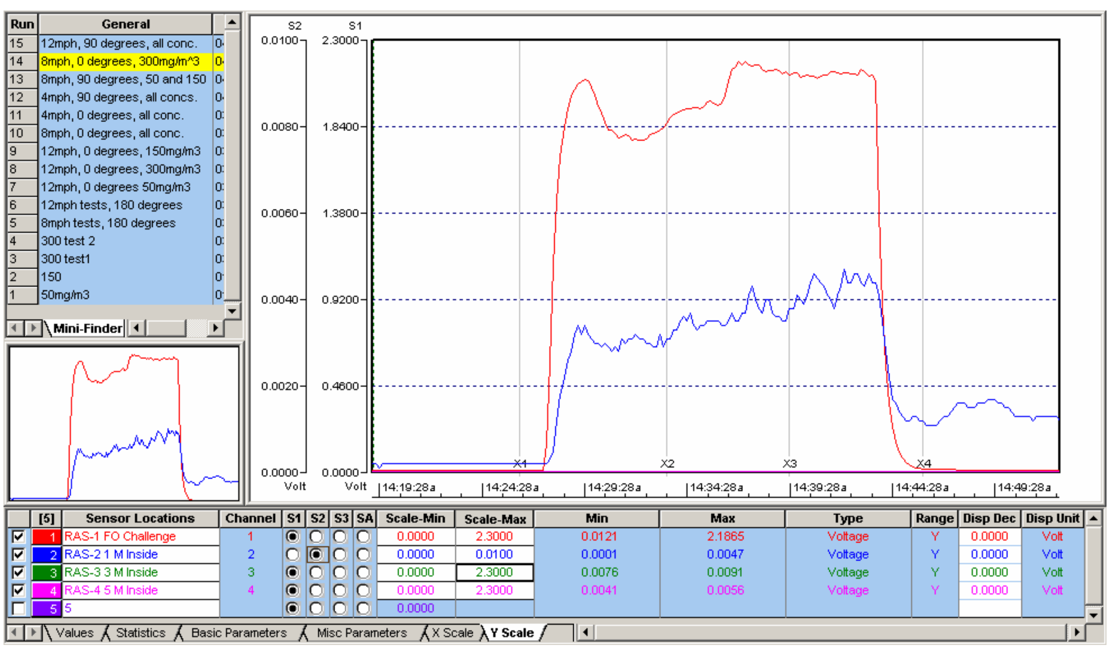

Figure A-5b. FO concentration profile for model gopher tortoise burrow testing at 8 MPH, 9O degrees, 1 concentration (300 mg/ m3).

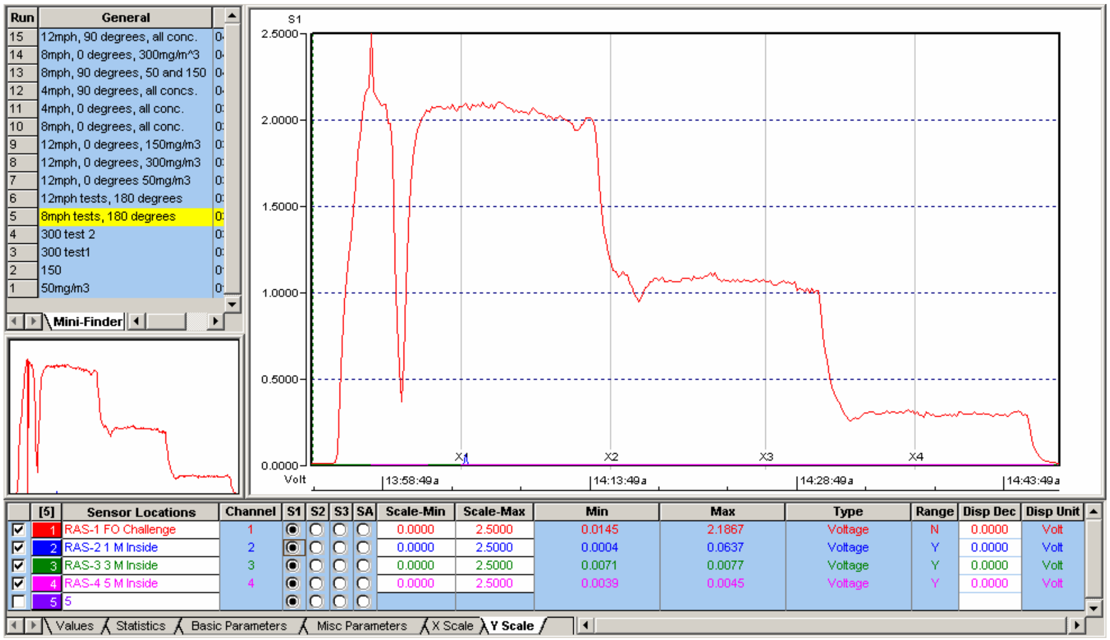

Figure A-6. FO concentration profile for model gopher tortoise burrow testing at 8 MPH, 180 degrees, 3 concentrations.

Table A-3. Measured FO concentrations and calculated descriptive statistics during FO challenge of model gopher tortoise burrow at 12 MPH for 3 Orientations and 3 Concentrations.

	0 Degrees		90 Degrees		180 Degrees	
Calculated Parameter	Challenge (mg/M^3)	1 Meter (mg/M^3)	Challenge (mg/M^3)	1 Meter (mg/M^3)	Challenge (mg/M^3)	1 Meter (mg/M^3)
Mean	51.07	-0.01	50.85	0.03	51.72	0.01
min	48.38	-0.03	48.05	0.00	49.77	0.00
max	54.10	0.01	55.64	0.06	54.26	0.03
median	51.06	-0.01	50.61	0.03	51.63	0.01
std-d	1.24	0.01	1.38	0.01	0.85	0.01
count	76.00	76.00	78.00	78.00	64.00	64.00
Mean	153.21	0.02	152.39	0.18	164.26	0.03
min	148.82	0.01	148.05	0.10	161.81	0.01
max	160.47	0.03	156.80	3.07	166.93	0.04
median	152.85	0.01	152.14	0.15	164.26	0.03
std-d	2.50	0.01	1.68	0.35	1.04	0.01
count	93.00	93.00	72.00	72.00	70.00	70.00
Mean	265.57	0.08	281.90	0.32	240.85	0.04
min	233.42	0.04	260.33	0.25	26.18	0.01
max	303.66	0.12	304.56	0.39	261.11	0.07
median	261.74	0.09	279.93	0.32	37.18	0.03
std-d	14.98	0.02	8.73	0.03	11.11	0.02
count	78.00	78.00	71.00	71.00	64.00	64.00

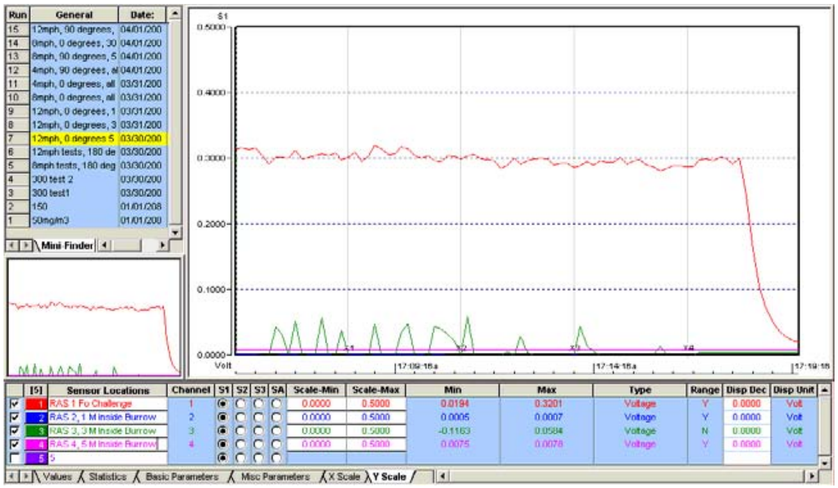

Figure A-7a. FO concentration profile for model tortoise burrow testing at 12 MPH, O degrees (50 mg/m^3).

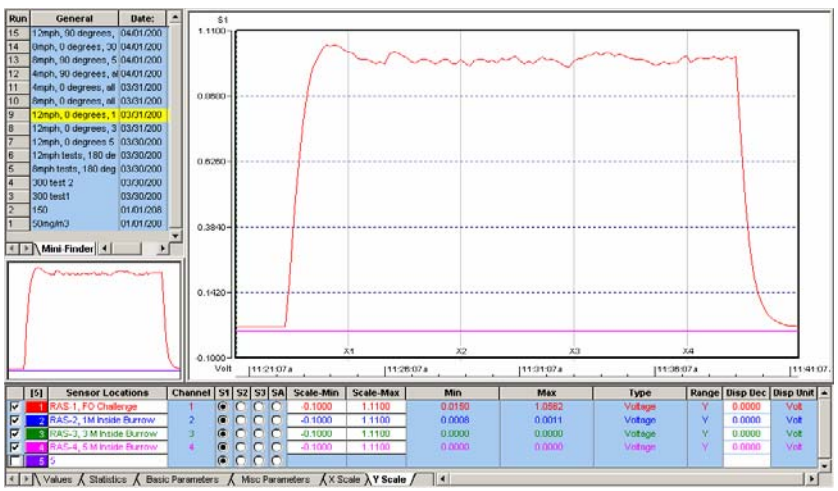

Figure A-7b. FO concentration profile for model tortoise burrow testing at 12 MPH, O degrees (150 mg/m^3).

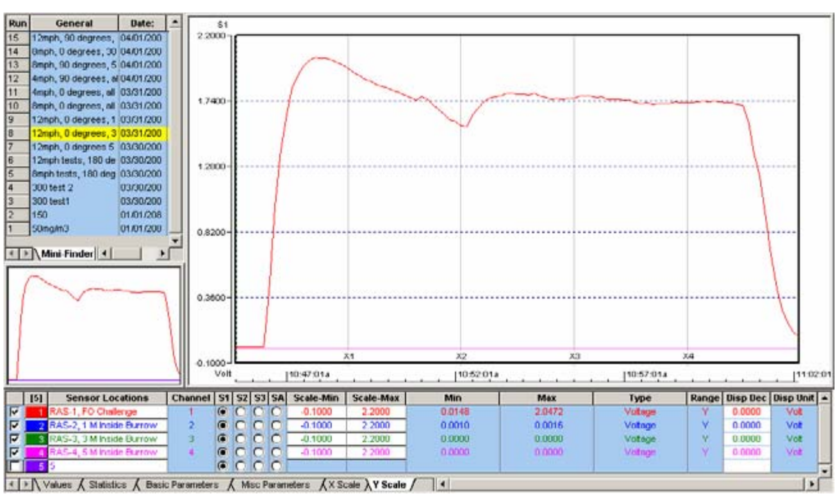

Figure A-7c. FO concentration profile for model tortoise burrow testing at 12 MPH, O degrees (265 mg/m^3).

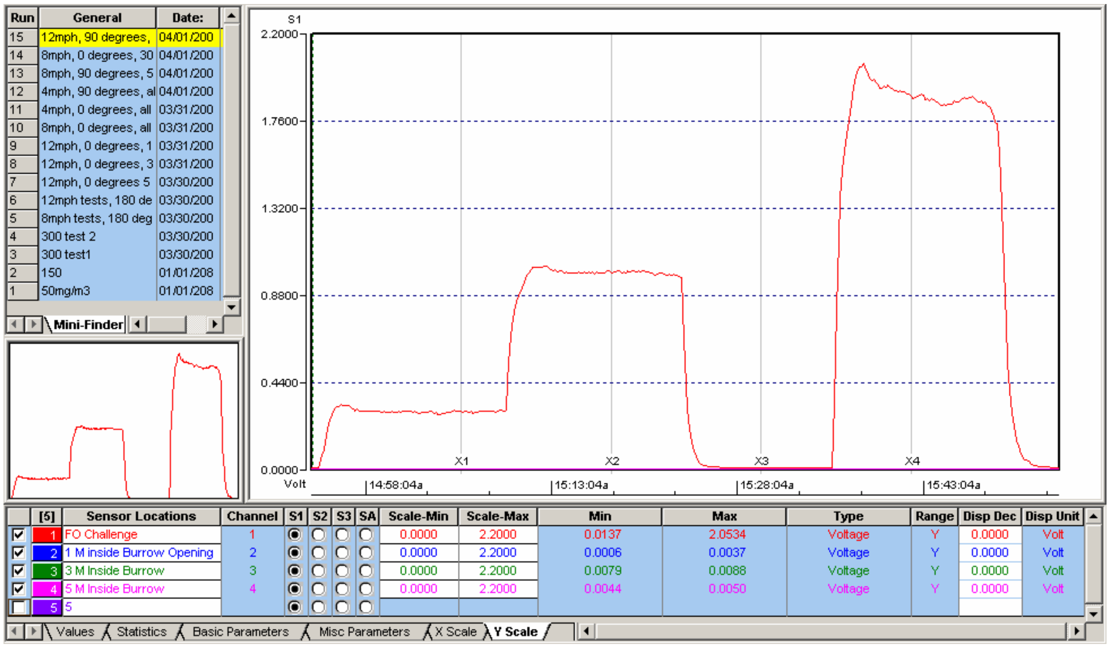

Figure A-8. FO concentration profile for model gopher tortoise burrow testing at 12 MPH, 9O degrees, 3 concentrations.

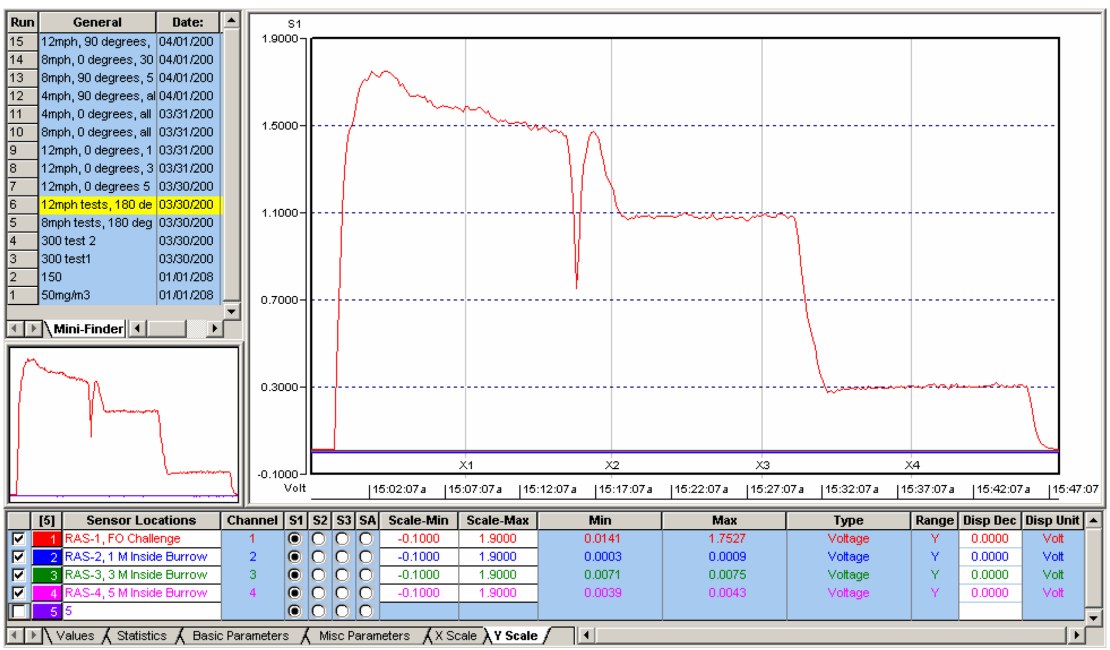

Figure A-9. FO concentration profile for model gopher tortoise burrow testing at 12 MPH, 180 degrees, 3 concentrations.

Appendix B: Data from Simulated Bat Maternal Colony Tree – Horizontal Orientation

Table B-1. Summary of average fog oil penetration into the model tree trunk cavity for each test with model in the horizontal position.

Wind Speed	Orientation (Degrees)	FO Challenge Concentration (mg/M3)	% Penetration Entrance	% Penetration 1 M Left	% Penetration 1 M Right
4MPH	0	51	105	111	88
4MPH	0	193	107	113	100
4MPH	0	282	111	115	102
4MPH	90	52	18	21	20
4MPH	90	173	9	12	7
4MPH	90	310	9	9	8
4MPH	180	99	36	14	13
4MPH	180	172	35	11	17
4MPH	180	300	35	10	26
8MPH	0	54	104	106	92
8MPH	0	208	105	107	85
8MPH	90	67	15	17	15
8MPH	90	260	8	9	7
8MPH	180	63	33	19	20
8MPH	180	246	29	10	13

Table B-2. Measured fog oil concentrations and percent penetration into model tree cavity at 4 mph, 0 degrees, with model in horizontal position.

Series	Parameter	Measured Fog Oil Concentration				Percent Fog Oil Penetration		
		FO Challenge mg/M^3	Inside Entrance mg/M^3	1 M Left mg/M^3	1 M Right mg/M^3	Entrance %	1 M Left %	1M Right %
4 MPH 0 $^{\circ}$	avg	51.2	53.5	56.9	44.8	104.6	111.1	87.5
	min	38.5	27.2	19.2	9.0	70.6	70.5	46.9
	max	90.2	74.3	82.5	57.9	82.4	110.9	70.2
	std-d	6.5	6.4	8.1	14.1			
	count	35.0	35.0	35.0	35.0			
	sample time (min.)	11.7	11.7	11.7	11.7			
4 MPH 0 $^{\circ}$	avg	193.3	212.6	218.0	192.6	110	112.8	99.6
	min	170.8	178.5	170.0	148.6	104.5	99.5	87.0
	max	206.2	222.4	228.9	203.4	107.8	111.0	98.6
	std-d	6.1	10.1	14.3	15.6			
	count	31.0	31.0	31.0	31.0			
	sample time (min.)	10.3	10.3	10.3	10.3			
4 MPH 0 $^{\circ}$	avg	282.1	314.2	323.5	288.6	111.4	114.7	102.3
	min	272.1	298.9	292.8	244.2	109.9	107.6	89.8
	max	309.8	318.9	344.2	319.2	102.9	111.1	103.0
	std-d	9.9	3.6	9.6	12.0			
	count	32.0	32.0	32.0	32.0			
	sample time (min.)	10.7	10.7	10.7	10.7			

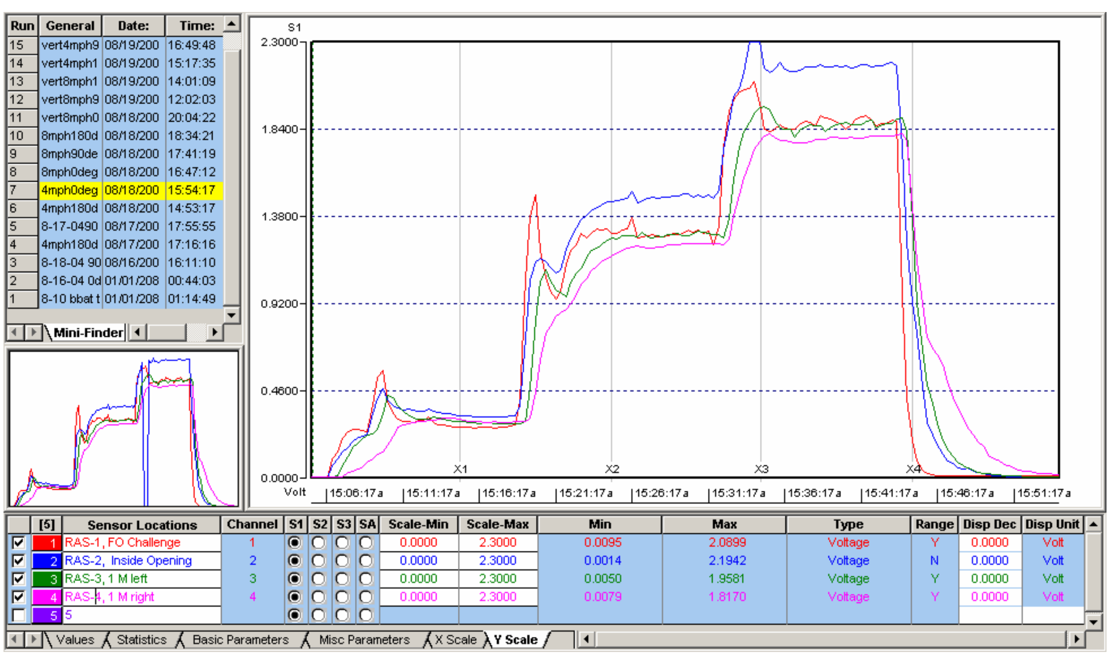

Figure B-1. FO concentration profile for model tree trunk cavity testing at 4 mph, 0 degrees, 3 concentrations.

Table B-3. Measured FO concentrations and percent penetration into model tree cavity at 4 mph, 90 degrees, with model in horizontal position.

Series	Parameter	Measured Fog Oil Concentration: FO Challenge mg/M^3	Inside Entrance mg/M^3	1 M Left mg/M^3	1 M Right mg/M^3	Percent Fog Oil Penetration: Entrance %	1 M Left %	1M Right %
4 MPH 90 ^{O}	avg	52.3	9.6	11.1	10.0	18.4	21.2	20.1
	min	44.9	8.6	10.4	9.4	19.1	23.2	21.9
	max	55.2	10.5	11.3	10.5	19.0	20.5	20.1
	std-d	2.9	0.4	0.2	0.4			
	count	30.0	30.0	30.0	30.0			
	sample time (min.)	10.0	10.0	10.0	10.0			
4 MPH 90 ^{O}	avg	173.2	16.2	20.0	12.9	9.4	11.5	7.5
	min	161.0	13.0	19.1	11.7	8.1	11.9	7.3
	max	181.7	17.6	20.8	14.2	9.7	11.5	7.8
	std-d	4.7	1.0	0.5	0.7			
	count	29.0	29.0	29.0	29.0			
	sample time (min.)	9.7	9.7	9.7	9.7			
4 MPH 90 ^{O}	avg	310.4	27.5	28.2	23.8	8.8	9.1	7.7
	min	295.8	18.0	22.8	13.3	6.1	7.7	4.5
	max	315.5	32.0	29.6	31.2	10.1	9.4	9.9
	std-d	3.8	3.5	1.5	6.0			
	count	39.0	39.0	39.0	39.0			
	sample time (min.)	13.0	13.0	13.0	13.0			

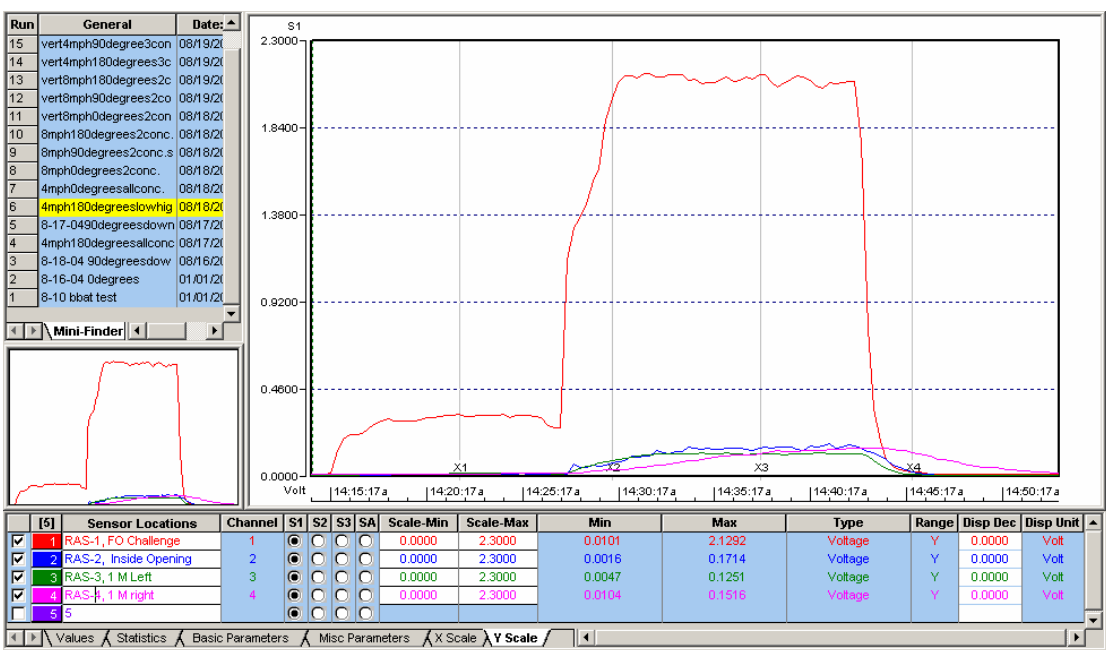

Figure B-2a. FO concentration profile for model tree trunk cavity testing at 4 mph, 90 degrees, 2 concentrations (50 mg/m^3 and 300 mg/m^3).

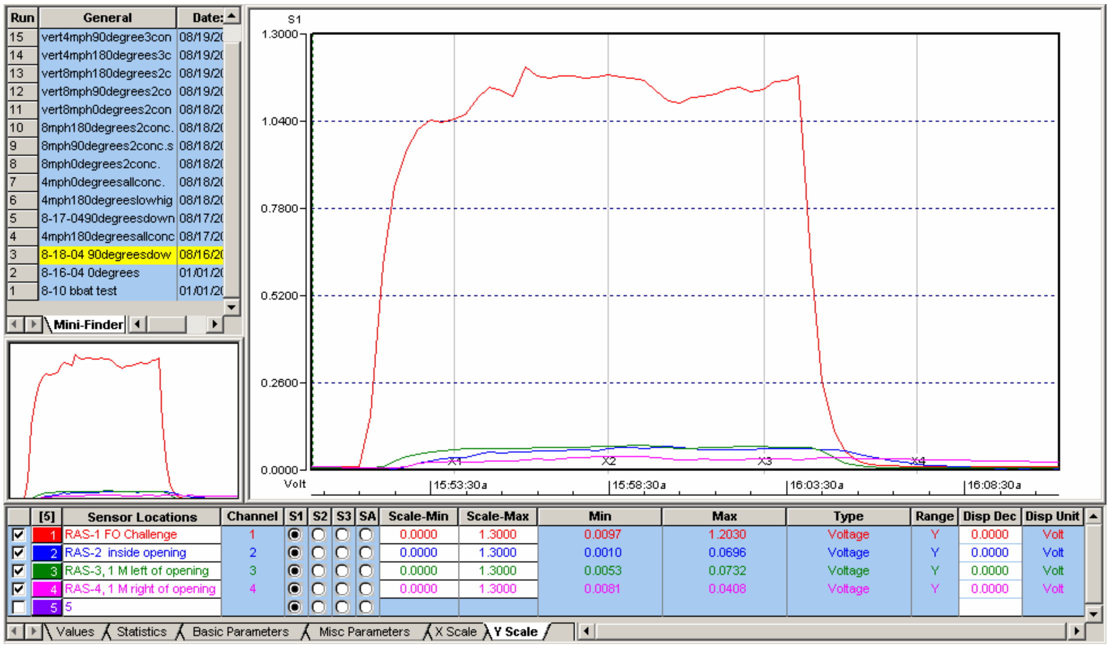

Figure B-2b. FO concentration profile for model tree trunk cavity testing at 4 mph, 90 degrees, 1 concentration (150 mg/m^3).

Table B-4. Measured FO concentrations and percent penetration into model tree cavity at 4 mph, 180 degrees, with model in horizontal position.

Series	Parameter	Measured FO Challenge mg/M^3	Fog Oil Concentration Inside Entrance mg/M^3	1 M Left mg/M^3	1 M Right mg/M^3	Percent Fog Oil Penetration Entrance %	1 M Left %	1M Right %
4 MPH 180 ^{O}	avg	99.5	35.5	13.9	12.5	35.7	13.9	12.6
	min	94.9	29.6	10.9	9.1	31.1	11.5	9.6
	max	104.2	38.0	14.6	16.4	36.5	14.0	15.7
	std-d	3.0	1.7	0.8	2.6			
	count	33.0	33.0	33.0	33.0			
	sample time (min.)	11.0	11.0	11.0	11.0			
4 MPH 180 ^{O}	avg	172.3	59.8	19.1	29.2	34.7	11.1	16.9
	min	146.3	51.9	15.3	16.7	35.5	10.5	11.4
	max	193.3	69.9	21.6	42.6	36.2	11.2	22.0
	std-d	13.0	4.7	1.3	7.3			
	count	43.0	43.0	43.0	43.0			
	sample time (min.)	14.3	14.3	14.3	14.3			
4 MPH 180 ^{O}	avg	299.6	104.6	30.0	76.8	34.9	10.0	25.6
	min	275.7	97.9	25.2	49.0	35.5	9.2	17.8
	max	325.7	114.8	32.3	88.6	35.3	9.9	27.2
	std-d	11.4	3.5	1.4	9.2			
	count	41.0	41.0	41.0	41.0			
	sample time (min.)	13.7	13.7	13.7	13.7			

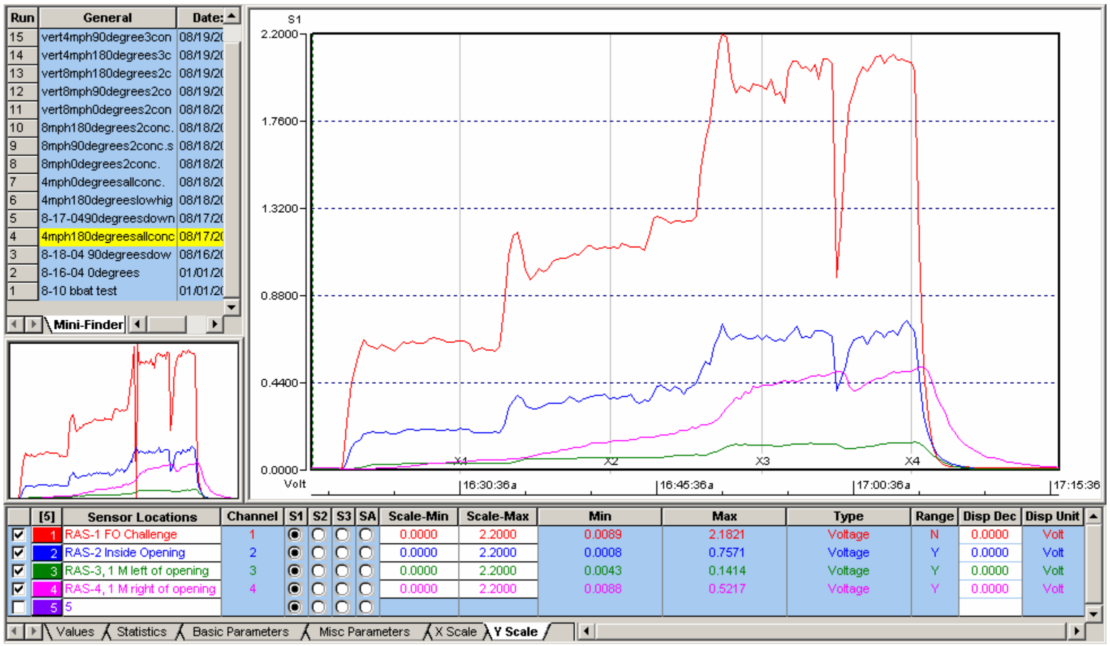

Figure B-3. FO concentration profile for model tree trunk cavity testing at 4 mph, 180 degrees, 3 concentrations.

Table B-5. Measured FO concentrations and percent penetration into model tree cavity at 8 mph, 0, 90, and 180 degrees, with model in horizontal position.

Series	Parameter	Measured FO Challenge mg/M^3	Fog Oil Concentration Inside Entrance mg/M^3	1 M Left mg/M^3	1 M Right mg/M^3	Percent Fog Oil Penetration Entrance %	1 M Left %	1M Right %
8 MPH 0 °	avg	54.3	56.7	57.8	50.0	104.5	106.5	92.1
	min	41.9	49.9	48.6	34.1	119.0	115.9	81.4
	max	57.4	59.2	60.0	54.9	103.1	104.6	95.6
	std-d	2.6	1.8	2.4	6.1			
	count	30.0	30.0	30.0	30.0			
	sample time (min.)	10.0	10.0	10.0	10.0			
8 MPH 0 °	avg	208.4	219.5	223.9	177.3	105.4	107.5	85.1
	min	194.1	209.2	198.7	66.8	107.8	102.4	34.4
	max	225.2	231.9	237.1	196.4	103.0	105.3	87.2
	std-d	9.7	6.1	7.6	33.1			
	count	37.0	37.0	37.0	37.0			
	sample time (min.)	12.3	12.3	12.3	12.3			
8 MPH 90 °	avg	67.4	10.1	11.8	10.1	15.0	17.5	15.0
	min	64.9	9.9	11.6	9.6	15.3	17.9	14.8
	max	71.5	10.5	12.0	10.3	14.7	16.7	14.4
	std-d	1.8	0.2	0.1	0.2			
	count	41.0	41.0	41.0	41.0			
	sample time (min.)	13.7	13.7	13.7	13.7			
8 MPH 90 °	avg	260.3	20.9	23.5	17.1	8.0	9.0	6.6
	min	247.1	18.3	22.5	13.0	7.4	9.1	5.2
	max	264.1	22.9	24.0	19.2	8.7	9.1	7.3
	std-d	3.0	0.8	0.3	2.0			
	count	37.0	37.0	37.0	37.0			
	sample time (min.)	12.3	12.3	12.3	12.3			
8 MPH 180 °	avg	63.5	21.2	12.0	12.8	33.4	18.9	20.2
	min	60.5	20.5	11.8	12.0	33.9	19.5	19.8
	max	72.7	24.0	12.9	13.3	33.0	17.7	18.3
	std-d	2.0	0.6	0.2	0.3			
	count	43.0	43.0	43.0	43.0			
	sample time (min.)	14.3	14.3	14.3	14.3			
8 MPH 180 °	avg	245.9	71.8	24.1	32.9	29.2	9.8	13.4
	min	237.0	68.3	23.6	22.0	28.8	10.0	9.3
	max	261.3	75.0	24.9	40.0	28.7	9.5	15.3
	std-d	5.8	1.8	0.3	5.0			
	count	30.0	30.0	30.0	30.0			
	sample time (min.)	10.0	10.0	10.0	10.0			

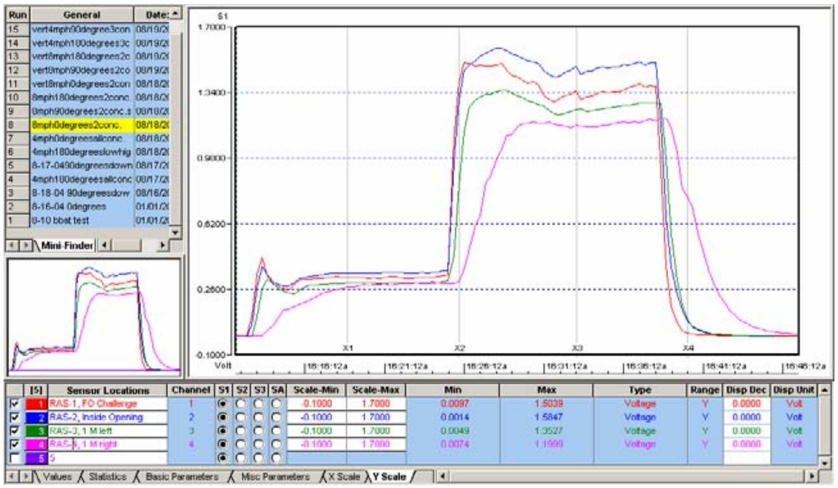

Figure B-4. FO concentration profile for model tree trunk cavity testing at 8 mph, 0 degrees, 2 concentrations (50 mg/m^3 and 200 mg/m3).

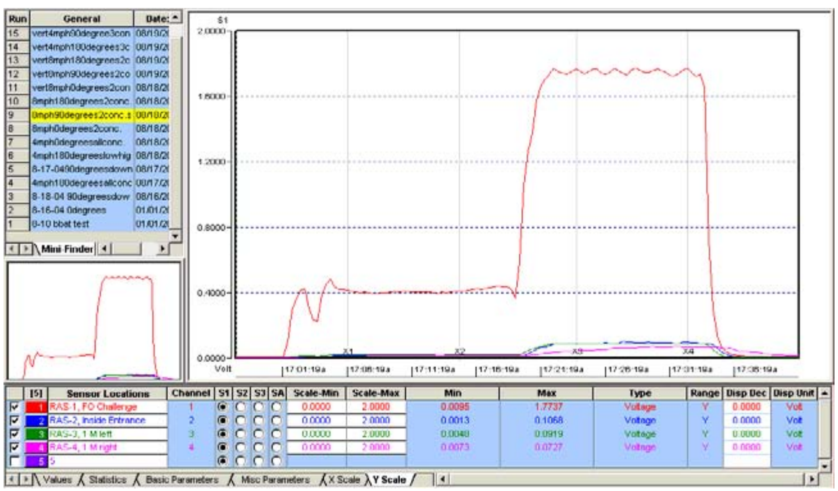

Figure B-5. FO concentration profile for model tree trunk cavity testing at 8 mph, 90 degrees, 2 concentrations, (65 mg/m^3 and 250 mg/m^3).

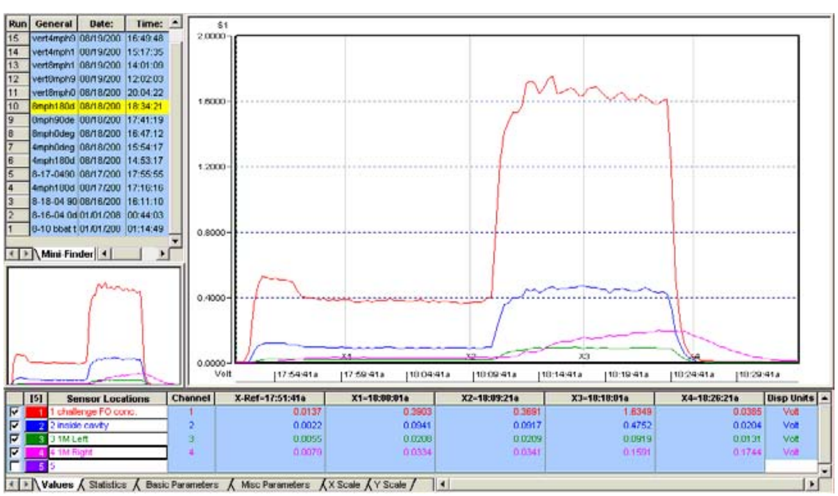

Figure B-6. FO concentration profile for model tree trunk cavity testing at 8 mph, 180 degrees, 2 concentrations (60 mg/m^3 and 250 mg/m^3).

Appendix C: Data from Simulated Bat Maternal Colony Tree – Vertical Orientation

Table C-1. Summary of average FO penetration into the model tree trunk cavity for each test with model in the vertical position.

Wind Speed	Orientation (Degrees)	FO Challenge Concentration (mg/M3)	% Penetration Entrance	% Penetration 1 M Below	% Penetration 1 M Above
4MPH	0	64	99	114	87
4MPH	0	177	100	107	85
4MPH	0	293	99	102	83
4MPH	90	64	15	18	15
4MPH	90	171	9	10	7
4MPH	90	293	7	8	6
4MPH	180	57	34	21	28
4MPH	180	178	31	11	24
4MPH	180	300	42	10	34
8MPH	0	61	109	109	82
8MPH	0	241	99	101	84
8MPH	90	60	16	18	16
8MPH	90	246	7	8	6
8MPH	180	48	32	22	21
8MPH	180	234	23	10	15

Table C-2. Measured FO oil concentrations and percent penetration into model tree cavity at 4 mph, 0 degrees, with model in vertical position.

Series	Parameter	Measured FO Challenge mg/M3	Fog Oil Concentration Inside Entrance mg/M3	1 M Below mg/M3	1 M Above mg/M3	Percent Fog Oil Penetration Entrance %	1 M Below %	1M Above %
	AVG	64.2	63.8	73.0	55.9	99.5	113.8	87.1
	MIN	60.8	61.8	70.9	32.5	101.5	116.6	53.5
V4MPH	MAX	68.3	65.2	75.1	64.4	95.5	110.0	94.3
0^{O}	STD-D	1.8	1.0	1.1	9.0			
	Count	35.0	35.0	35.0	35.0			
	sample time (min.)	11.7	11.7	11.7	11.7			
	AVG	176.9	177.1	190.3	150.5	100.1	107.5	85.0
	MIN	167.6	170.9	160.9	113.5	101.9	94.1	67.7
V4MPH	MAX	197.5	193.9	204.6	159.4	98.2	105.5	80.7
0^{O}	STD-D	10.4	6.7	8.6	13.2			
	Count	31.0	31.0	31.0	31.0			
	sample time (min.)	10.3	10.3	10.3	10.3			
	AVG	292.5	289.9	297.8	241.6	99.1	101.8	82.6
	MIN	285.4	280.7	257.1	194.6	98.4	90.1	68.2
V4MPH	MAX	303.4	299.1	308.1	255.4	98.6	101.5	84.2
0^{O}	STD-D	4.1	4.8	10.0	16.4			
	Count	34.0	34.0	34.0	34.0			
	sample time (min.)	11.3	11.3	11.3	11.3			

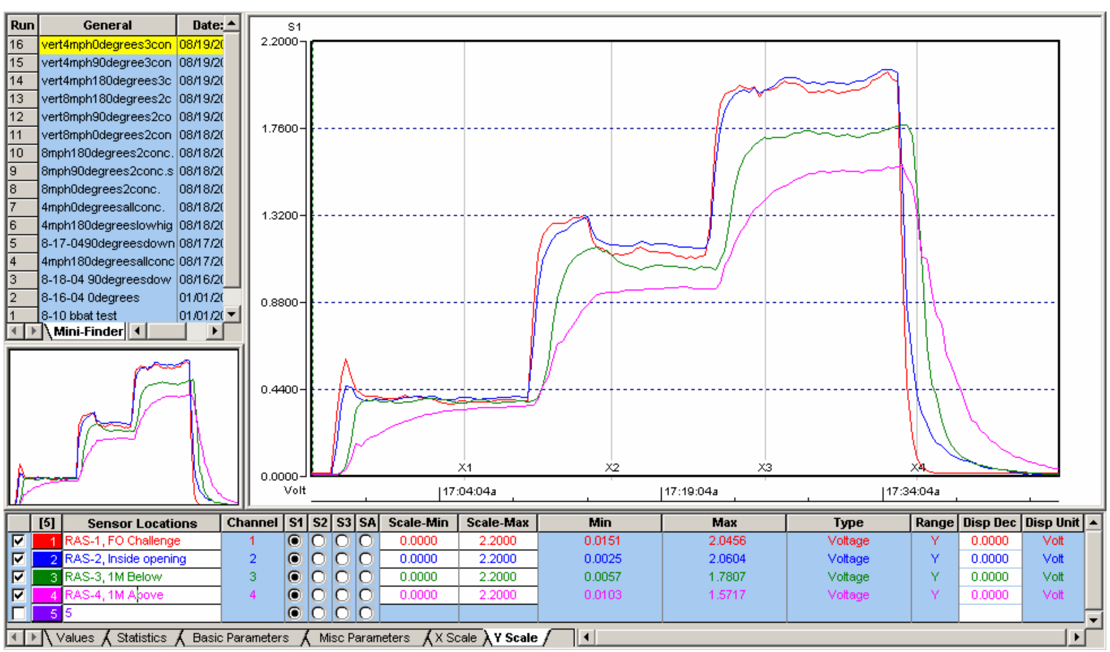

Figure C-1. FO concentration profile for model tree trunk cavity, vertical testing at 4 mph, 0 degrees, 3 concentrations.

Table C-3. Measured FO concentrations and percent penetration into model tree cavity at 4 mph, 90 degrees, with model in vertical position.

Series	Parameter	Measured FO Challenge mg/M^3	Fog Oil Concentration Inside Entrance mg/M^3	1 M Below mg/M^3	1 M Above mg/M^3	Percent Fog Oil Penetration Entrance %	1 M Below %	1M Above %
V4MPH 90 ^{O}	AVG	64.3	9.8	11.3	9.6	15.3	17.5	15.0
	MIN	57.3	9.2	11.0	8.9	16.1	19.1	15.6
	MAX	68.6	10.1	11.5	10.1	14.7	16.8	14.7
	STD-D	2.6	0.2	0.1	0.3			
	Count	36.0	36.0	36.0	36.0			
	sample time (min.)	12.0	12.0	12.0	12.0			
V 4MPH 90 ^{O}	AVG	171.0	14.6	16.4	12.6	8.6	9.6	7.3
	MIN	165.7	14.1	15.9	10.3	8.5	9.6	6.2
	MAX	199.8	15.4	17.3	13.5	7.7	8.7	6.7
	STD-D	6.4	0.3	0.4	0.9			
	Count	34.0	34.0	34.0	34.0			
	sample time (min.)	11.3	11.3	11.3	11.3			
V4MPH 90 ^{O}	AVG	293.2	20.8	22.9	18.0	7.1	7.8	6.2
	MIN	288.4	20.0	22.1	17.7	6.9	7.7	6.1
	MAX	297.9	23.2	24.4	18.9	7.8	8.2	6.3
	STD-D	2.7	0.7	0.5	0.2			
	Count	35.0	35.0	35.0	35.0			
	sample time (min.)	11.7	11.7	11.7	11.7			

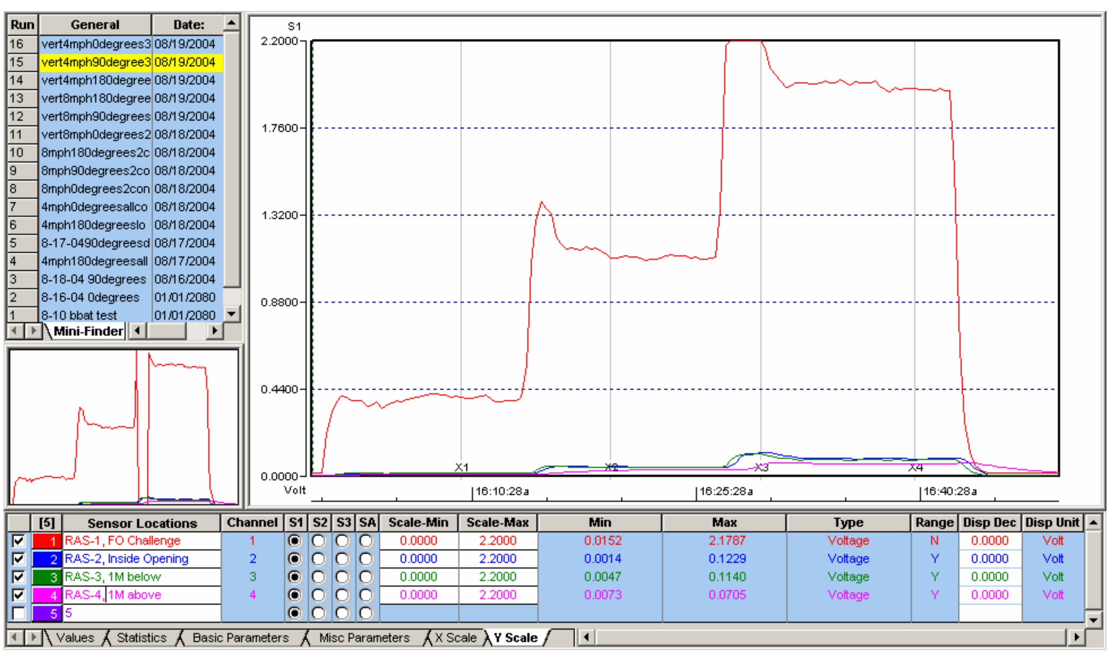

Figure C-2. FO concentration profile for model tree trunk cavity, vertical testing at 4 mph, 90 degrees, 3 concentrations.

Table C-4. Measured FO concentrations and percent penetration into model tree cavity at 4 mph, 180 degrees, with model in vertical position.

Series	Parameter	Measured FO Challenge mg/M³	Fog Oil Concentration Inside Entrance mg/M³	1 M Below mg/M³	1 M Above mg/M³	Percent Fog Oil Penetration Entrance %	1 M Below %	1M Above %
V4MPH 180 °	AVG	56.6	19.5	11.6	15.6	34.4	20.5	27.5
	MIN	52.3	17.6	11.4	11.4	33.6	21.9	21.8
	MAX	64.1	24.2	12.1	17.4	37.7	18.9	27.1
	STD-D	3.0	1.5	0.2	1.5			
	Count	34.0	34.0	34.0	34.0			
	sample time (min.)	11.3	11.3	11.3	11.3			
V4MPH 180 °	AVG	178.3	55.5	19.7	42.3	31.2	11.0	23.7
	MIN	170.1	39.9	18.0	29.0	23.4	10.6	17.1
	MAX	247.0	72.6	21.1	51.9	29.4	8.6	21.0
	STD-D	13.3	7.4	0.8	5.3			
	Count	40.0	40.0	40.0	40.0			
	sample time (min.)	13.3	13.3	13.3	13.3			
V4MPH 180 °	AVG	300.2	127.1	30.1	101.5	42.3	10.0	33.8
	MIN	289.2	112.7	29.1	92.3	39.0	10.0	31.9
	MAX	309.8	141.4	31.0	110.3	45.6	10.0	35.6
	STD-D	4.4	7.1	0.5	4.8			
	Count	35.0	35.0	35.0	35.0			
	sample time (min.)	11.7	11.7	11.7	11.7			

Figure C-3. FO concentration profile for model tree trunk cavity, vertical testing at 4 mph, 180 degrees, 3 concentrations.

Table C-5. Measured FO concentrations and percent penetration into model tree cavity at 8 mph, 0, 90 and 180 degrees, with model in vertical position.

Series	Parameter	Measured FO Challenge mg/M^3	Fog Oil Concentration Inside Entrance mg/M^3	1 M Below mg/M^3	1 M Above mg/M^3	Percent Fog Oil Penetration Entrance %	1 M Below %	1M Above %
V8MPH 0 ^{O}	avg	61.0	66.1	66.5	49.8	108.5	109.1	81.7
	min	53.2	60.3	48.6	22.2	113.4	91.3	41.7
	max	63.3	68.7	69.5	57.4	108.6	109.8	90.7
	std-d	1.7	1.6	3.3	10.1			
	count	37.0	37.0	37.0	37.0			
	sample time (min.)	12.3	12.3	12.3	12.3			
V8MPH 0 ^{O}	avg	241.1	239.9	244.1	203.1	99.5	101.2	84.2
	min	233.5	232.0	221.0	121.3	99.4	94.7	51.9
	max	251.5	249.5	253.7	218.7	99.2	100.9	86.9
	std-d	5.5	4.9	6.1	25.1			
	count	42.0	42.0	42.0	42.0			
	sample time (min.)	14.0	14.0	14.0	14.0			
V8MPH 90 ^{O}	avg	60.1	9.4	10.8	9.7	15.7	17.9	16.1
	min	52.7	9.1	10.5	9.0	17.4	19.9	17.0
	max	68.1	9.6	11.0	10.0	14.1	16.1	14.6
	std-d	3.4	0.1	0.1	0.3			
	count	43.0	43.0	43.0	43.0			
	sample time (min)	14.3	14.3	14.3	14.3			
V8MPH 90 ^{O}	avg	246.2	17.5	19.1	15.2	7.1	7.8	6.2
	min	237.7	17.0	18.5	11.7	7.1	7.8	4.9
	max	261.4	18.0	19.6	16.2	6.9	7.5	6.2
	std-d	5.9	0.2	0.2	1.3			
	count	38.0	38.0	38.0	38.0			
	sample time (min)	12.7	12.7	12.7	12.7			
V8MPH 180 ^{O}	avg.	48.4	15.4	10.4	10.0	31.8	21.5	20.6
	min.	44.4	13.5	10.2	7.8	30.5	23.1	17.7
	max	52.0	19.8	10.7	11.7	38.1	20.6	22.6
	std-d	1.9	1.2	0.1	1.2			
	count	48.0	48.0	48.0	48.0			
	sample time (min)	16.0	16.0	16.0	16.0			
V8 MPH 180 ^{O}	avg.	233.7	54.8	23.0	34.7	23.4	9.8	14.8
	min.	220.6	44.0	21.1	18.5	20.0	9.6	8.4
	max	250.8	68.9	24.2	41.7	27.5	9.7	16.6
	std-d	8.7	5.8	0.8	6.6			
	count	35.0	35.0	35.0	35.0			
	sample time (min)	11.7	11.7	11.7	11.7			

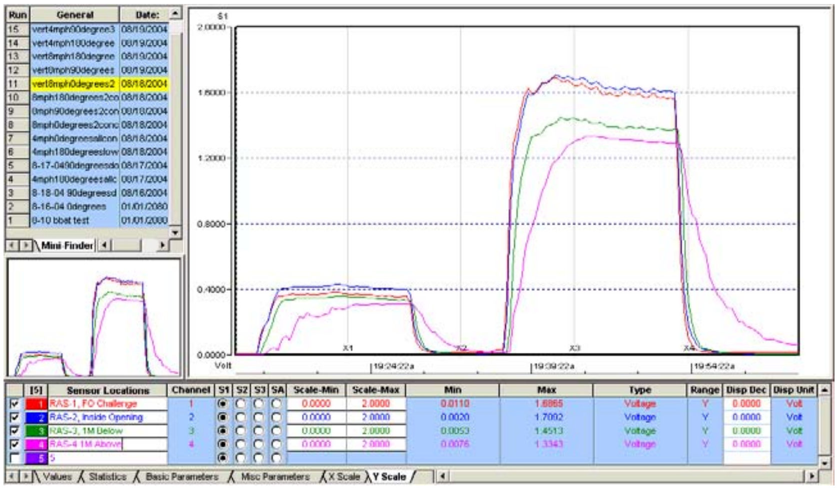

Figure C-4. FO concentration profile for model tree trunk cavity, vertical testing at 8 mph, 0 degrees, 2 concentrations.

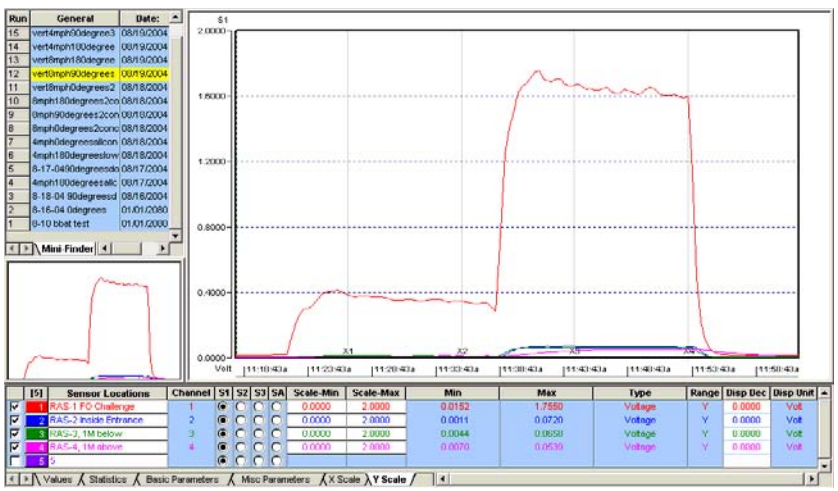

Figure C-5. FO concentration profile for model tree trunk cavity, vertical testing at 8 mph, 90 degrees, 2 concentrations.

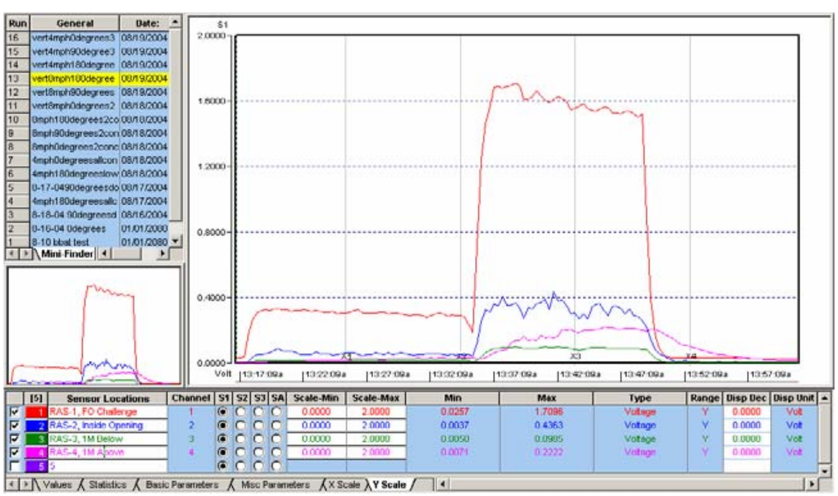

Figure C-6. FO concentration profile for model tree trunk cavity, vertical testing at 8 mph, 180 degrees, 2 concentrations.

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14. ABSTRACT

The gopher tortoise (*Gopherus polyhemus*) and the Indiana bat (*Myotis sodalist*) are species found on many military installations. The Indiana bat is endangered throughout its range, and the gopher tortoise is threatened in its westernmost distribution and at risk everywhere else. On installations where troop readiness training is conducted, an important component of realistic troop readiness training is the generation of obscurant material and the conduct of maneuvers under obscurant cover. Fog oil has long been deployed for visual obscuration training, and the effect of such obscurants on these species is unknown. As a preliminary step prior to instituting toxicological studies, a laboratory simulation was performed of the capability of the fog oil smoke to penetrate the living space of these species, the tortoise burrow and the hollow-tree location of a bat maternity colony. The fog oil smoke did not enter the simulated tortoise burrow in significant concentrations, but smoke concentrations in the simulated tree cavity approached ambient levels. This suggests that tortoise burrows do not need to be studied in situ, and that tortoises may be considered protected while in the burrow. Bat maternal colony sites, however, should not be considered protected from smoke entry to any significant degree.

15. SUBJECT TERMS

fog oil obscurant	Indiana bat	bat colony trees
gopher tortoise	tortoise burrows	threatened and endangered species

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